THE

THEOLOGICAL,

PHILOSOPHICAL AND MISCELLANEOUS

WORKS

OF THE

REV. WILLIAM JONES, M.A. F.R.S.

IN TWELVE VOLUMES.

TO WHICH IS PREFIXED,

A SHORT ACCOUNT

OF HIS

LIFE AND WRITINGS.

VOL. IX.

LONDON:

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Η ΠΕΙΡΑ ΣΦΑΛΕΡΗ, Η ΚΡΙΣΙΣ ΧΑΛΕΠΗ.

TO THE RIGHT HON.

CHARLES JENKINSON, Esq.

SECRETARY AT WAR, AND

ONE OF HIS MAJESTY'S MOST HONOURABLE PRIVY COUNCIL.

SIR,

If I ask leave to inscribe the following work to your name, it is with an honest desire of taking the only opportunity in my power to discharge a very small part of a just debt; and an author, who is venturing upon a new path of science, may be excused if he wishes to be introduced to the world under the auspices of some powerful friend, who has acquired more fame, and is entitled to more respect than himself.

To

To the honour which you derive from the rank and antiquity of your Family, and your own many excellent qualifications, His Majesty has been pleased to add that of one of the highest offices in this kingdom; and you have reflected honour upon your office by a faithful and diligent execution of the duties belonging to it. As an Englishman, and a lover of my country, I think myself under obligations to you for your public services to it at this critical time, when able heads and busy hands are so necessary to its preservation.

All men are witnesses to the honours of your riper years, in which you have passed through almost every department of the State; but it was my lot, Sir, to be a witness to the prudence of your youth. While others of your own age were wasting their health, their fortunes, and their precious hours upon idle and corrupting amusements, you were busy

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in the cultivation of a strong and fruitful mind: you never lost sight of the great objects of your education, but improved your talents by an unwearied application to every branch of useful and ornamental learning, and prepared yourself for rendering to your country those eminent services, of which we are now reaping the advantage. I have observed, not without some wonder, that in an age when calumny is become a traffick, and official dignity is thought to be synonymous with guilt, it has been your peculiar felicity to stand uncensured, as if you were suspected to be invulnerable.

Perhaps I may seem to be in need of an apology for presenting to a Gentleman engaged in the duties of the War-office, a Treatise on Philosophy; a study more nearly related to the gown than to the sword; but I need not remind you, Sir, that Philosophy is a mistress of arms as

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if the great question is determined concerning the Nature of those Causes, or First Principles, which are established by the Creator in the Constitution of the Natural World.

The ingenious Author of one of our modern Systems of Philosophy, objected to the use of the terms *First Principles*, as if I had been guilty of an impropriety in the Title of my work: but the expression is allowable, and seemed to convey my meaning better than any other I could find. It was used by Dr. Desaguliers, a writer well skilled in experimental philosophy; and his words are cited in the course of my work*. "Attraction and repulsion," says he, "seem to be settled by the great Creator as FIRST PRINCIPLES in Nature; that is, as the *first of second causes*." Now, as my design in that work was to demonstrate the use of Second Causes in Nature, and to point out those which have the first place, I took the words in the same sense in which they had been used by Dr. Desaguliers, and called my treatise An Essay on the *First Principles*, that is, on the first of those *Second Causes* whereby

* Oxford Edit. p. 65. Dublin Edit. p. 63.

whereby we endeavour to account for the operations of Nature.

Every author, when he sits down to write, wishes to give general satisfaction: but to please all readers in a subject of such deep inquiry, and concerning which there always have been different and contradictory opinions, would have been a hopeless undertaking. It was justly apprehended, at the publication of the work, that a treatise, presuming to interfere with the very foundations of Philosophy, raising questions about Causes supposed to be already established and explained as far as they could be, and proceeding on Principles new to some, and exploded by others, could never make its way without some interruption. The author, therefore, prepared himself for the worst; and gave up, at the first step, every prospect of popular encouragement—a sacrifice which every man must be ready to make, who thinks he has any thing great and useful to propose; especially in an age more addicted to the airy amusements of the fancy, than to the serious and painful disquisitions of solid learning. However, I had the satisfaction to find, after waiting for several years, that although some observations have been offered

to me, of which I shall speak hereafter, nothing has been advanced that affects the general plan of the work; and that it has been attentively considered by readers of capacity and candour, both at home and abroad.

Having observed very early in life, from a few obvious examples, that great effects are produced in Nature by the *action of the elements on one another*, I was so much encouraged by the apparent usefulness of this principle, and so soon convinced of its importance in the several chief branches of Natural Philosophy, that I determined to pursue it as far as I should have light and opportunity; and to examine, to the utmost of my ability, whether the same powers which obtain so evidently in some cases, might not be extended with advantage to others—that all philosophy might be reduced to one simple and universal law, the Natural Agency of the Elements.

But, how pleasant soever this inquiry might be in the prospect, I found, by degrees, that there were many great difficulties in the way to discourage me in the prosecution of it. For, first, it was generally believed by learned men, that a Vacuum had actually been demonstrated by our great Newton; and, consequently, that no powers were to be admitted

ted in Nature but such only as were consistent with that principle. It must be allowed, that this celebrated author, by the help of numerous and judicious experiments, settled all the laws of communicated motion, computed the resistance of fluids, dissected the subtile body of the light, and, with indefatigable industry and sagacity, discovered certain constant and regular effects, to which he gave the names of Attraction and Repulsion, and, by the most profound skill in Geometry, demonstrated the proportions of those effects in almost all possible cases, and shewed by experiments how the phenomena of Nature agree with his calculations. This is his philosophy, which stands upon the firm basis of Demonstration: but as to the Demonstration of a Vacuum, he left it in suspense, as we shall see hereafter: and as to the *Causes* of those effects above mentioned, he advised future philosophers to inquire farther into them; confessing, in his latest works, that what he calls *Gravity* might, for any thing he knew to the contrary, be the effect of *Impulse*.

He therefore did not believe that his philosophy precluded such an inquiry as that of

the Essay. But, as many of his followers, and some of his readers, had seriously taken up such a persuasion, I foresaw that my proposed investigation of Natural Causes would be at first but coldly regarded, if not absolutely condemned, as an undertaking, at best superfluous, and perhaps totally groundless and absurd. This was the first difficulty I had to encounter; and it was great enough, without the addition of a second.

But there remained another difficulty, equally formidable, and more likely to defeat all my endeavours; as rendering it next to impossible that I should ever get to the ear of the public. The Agency of the Elements, the principle which has engaged my attention, and to the study of which I had determined to dedicate the chief labours of my life, had been already taken up, and maintained in a manner neither acceptable nor satisfactory, by Mr. Hutchinson, an author of a singular cast, and under a state of final reprobation with the learned of this kingdom; whom every scribbler can deride, and every incipient in philosophy can confute. This was very much against me: for there

there wanted nothing to render all my reasonings abortive, but to represent me as a follower or favourer of Mr. Hutchinson.

To get over the first of these difficulties, I thought it was my duty to examine impartially, and then to represent as faithfully as I could, the true state of the question; and to give as much weight as should be found due to all the experiments and doctrines that were supposed to militate against my projected inquiry into the Agency of the Elements. This gave occasion to the preparatory work I have already mentioned, which I called *An Essay on the First Principles of Natural Philosophy*. Its object was to consider, 1. The *Mechanism of Nature*, and, under this head, shew the insufficiency of the objections which had been raised against the doctrine by Dr. Clarke and other learned writers: to shew how motion might consist with a Plenum, or space filled with fluid matter: and to prove yet farther, from actual observation, that the presence of resisting Matter was, under certain circumstances, not an obstruction, but even necessary in itself to preserve in bodies an undecaying motion. 2. To shew, that, so far as unmechanical causes had been proposed to answer

the purpose of first principles, they were neither well understood by those who had espoused them, nor capable of being explained from the nature of them: that it was not determined whether they were properly causes or effects, material powers or immaterial; for that some learned persons had inclined to one side, some to the other; and that, if considered as immaterial, neither experiment nor geometry had demonstrated them in that capacity. 3. To produce some positive proofs of a matter in the heavens, and that there is a subtile medium in the pores of all bodies; with some examples of its action and power in producing the effects of cohesion and repulsion. 4. To shew the reasonableness of an impulsive Agency in Nature, from the general attestation of antiquity, both sacred and profane; and also from the judgment of some of the most eminent scholars among the moderns. To these four Books, an Appendix of Papers was subjoined, to carry on and illustrate some points which had been started in the course of the work.

Important as many of the questions are which came under consideration in that Essay, I never met with any thing worth my notice against it, in print or in manuscript, for

for several years. As the subject was seldom long out of my mind, I took an opportunity, when I was abroad, of trying how it would appear to two learned gentlemen with whom I conversed; who being divested of English prejudices, and strangers to my name and labours, could be influenced neither by fear nor favour. One of them admitted the truth of what I proposed; saw the reasonableness and reality of an impulsive agency; and declared he thought the time would come when it would be generally admitted. The other insisted, that the fame of Newton had given such weight to a contrary opinion, that men would never listen to this, neither could he himself be inclined to it.

Of late, some gentlemen of Cambridge, whom I have reason to honour for their learning, while I cannot but esteem them cordially for their candour and liberality, have considered the book with the attention due to the importance of its object. From their learned criticisms, I am convinced of what I was always forward enough to believe, that the Essay has not only its inaccuracies, but some errors which occasionally affect the argument, and also some positions, which are either precarious from the depth and difficulty

of

of the subject, or stand in need of a farther explanation, which it is partly the business of the following work to give; and there is unfortunately added a false calculation from an error of the press, without any notice given of it. All these things I take to myself as the writer of the book; but at the same time I must say, in justice to the cause, that the remarks take the defensive part, and that I find nothing to invalidate the leading principle of the work. I rather find, that the agency, for which I pleaded twenty years ago as an adventurer in the argument, is now better understood, from the progress which has been made since that time in the experimental knowledge of the elements; and I venture to predict, that it must be more generally admitted by the learned, when it shall have had the good fortune to have been farther considered.

By some, who were less liberal in their manners and sentiments, and pronounced too hastily upon the case, without appearing to me to have taken due pains to understand it, it was given out, soon after the publication of the work, that I had only revived the arguments of Leibnitz against Dr. Clarke; and, consequently, that what I had advanced

had

had been already refuted long before. But any person who compares the matter of the Essay with the controversial papers of Mr. Leibnitz, will find that I had no assistance from his arguments, and that I have no concern with the fate of his system, which savours too much of metaphysical temerity to recommend itself to my taste. The great argument for a vacuum from the *vis inertiæ*, and the resistance of fluids, urged by Dr. Clarke, received so weak an answer from that celebrated mathematician, that he was evidently perplexed, and knew not how to get over the difficulty, which he rather evades than attempts to answer *. But this great objection to the agency of impelling fluids, is taken off in the Essay, by the introduction of a very easy distinction, illustrated with a few plain facts, which shew, that if the argument is taken in that general sense for which it seems to have been intended, it proves too much: for it supposes a case to be impossible in Nature, which really happens in all the instances there produced; as the reader may see, if he will give himself the

* See the Collection of Papers between Mr. Leibnitz and Dr. Clarke, p. 127, 185, 227.

the trouble of recurring to them *. The facts I allude to are given as so many actual examples of an unresisted motion, from an impelling fluid in a resisting medium: the most palpable of which is a machine, moving on the principle of the smoke-jack, carrying two lights, which begin to move of themselves, and, consequently, retain undiminished the motion they acquire. The instrument was taken from the Entretiens Physiques of Pere Regnault, where I found it introduced for the trifling purpose of giving an alternate motion to some magnetical puppets, by means of two lighted candles in a pair of scales. The form of the instrument was altered in such a manner as to accommodate it better to the subject to which it is applied in the Essay.

The argument to demonstrate a vacuum, is built (as mathematicians well know) on this observation; that all fluids resist a moving body in the direct ratio of their densities. The body communicates to the fluid the motion it had received; what it communicates it loses; and a body which continues to lose its motion, must in time lose the whole,

* See Book i. c. 5.

whole. But if, on the contrary, it does not appear to lose any of its motion, it follows, that it must either move in a vacuum, or in a medium of no sensible density; which comes to the same. This argument, which appears very strong, is applicable only to such bodies as are put into an unnatural state by some violence; as when they derive their motion from a projectile force: and it would be universal, if all bodies were moved on that principle; but when bodies are moved on other principles, another law takes place. For, let an impelling fluid be the primary cause of motion in any moving body; and that body will then meet no such resistance from the same fluid as tends to deprive it of its motion; it being impossible, as implying a contradiction, that a cause of motion should resist the motion which it causes. Now, apply this distinction to the machine. The impulse of the air, rarefied by fire, against the vanes, is the cause of its revolution: therefore, the resistance of the other air, in which it moves, is of no account as an obstruction in this case, whatever it may be in other cases. It is true that the machine, as it revolves, communicates motion to the air; but it receives more than it communicates,

municates, and thence loses nothing by the communication.

Air and fire, by the established laws of Nature, have a motion of their own, prior to the motion of the machine. The motion does not observe the law of projectiles, but is contrary to it. The motion of projectiles is from more to less: the motion of air and fire is from less to more; as when the fire of a spark increases to the fire of a whole city: or, the motion first excited in a little corn of gun-powder, gives fire to the whole charge of the mine; in which cases, the motion is not diminished, but increased by communication. It has been said, that if the resistance of a fluid, arising from its *vis inertiæ*, is diminished, the quantity of matter must be diminished: but there appears to be another way of diminishing the resistance; for, let the fluid in question act as an impelling cause to a moving body, and its resistance, with respect to the same body, becomes of no account: it is in a manner annihilated, and that without removing a single particle of matter. The like is true of all floating bodies; where the motion of the fluid conspires with the motion of the body: for, when this happens, the body moves with the velocity

velocity of the fluid, and loses nothing by communication. The same will hold in all other cases of the kind. In fluids which have a motion of their own, bodies under proper circumstances will not lose motion, but acquire it. If the matter of the heavens has a motion of its own, the planets will thence derive their revolutions, instead of being retarded by it.

As it was a practice with many writers in the last age to deny the existence of any fluid matter more subtile than air, I thought it necessary to consider their arguments. This gave occasion to a report, that I had revived the subtile matter of Descartes, whose hypothesis of the Vortices had long been out of repute. But this was not true: I had, indeed, insisted on the reality of a subtile matter; but had rejected that of Descartes, and had taken occasion to advance what I thought an insuperable objection, viz. that he had ascribed a motion to it not verified by any one instance in Nature, so far as I could then perceive. I find (though I could scarcely think it possible under the present state of philosophy), that there are some learned men to this day, who are strongly disaffected to all subtile mediums. The

learned

learned Spaniard, Feyjoo, several of whose pieces have lately made their appearance in an English translation, offers a mechanical reason, to prove that all subtile matters must be impotent and useless. The more fluid any matter is (says he), the less is its impulsive force. A stream of water gives a less violent shock to a wall, than a solid body of equal dimensions; and air, a much less than water: a subtile matter more fluid than air would impress a weaker impulse; and if there is any matter infinitely fluid, its impulse must totally vanish: therefore, no body can be moved by the impulse of a subtile matter. This looks fair; but, when the case is truly stated, the author's reasoning may be inverted. Fluid matter can move with greater velocity in proportion to its fluidity: water flows faster than oil, and air faster than water. A stream of air will give a more violent impulse to a leaden bullet than any stream of water of the same dimensions, from its velocity: whence a body of infinite fluidity will have infinite velocity; and from its infinite velocity its force will be infinite. This conclusion is contradictory in terms to that of the learned Spaniard; but it is much nearer to the truth as it is in nature. Nobody doubts

doubts but that the matter of lightning is more fluid than the matter of air; yet, from its velocity, we see it shatter stone-buildings, and rend oak-trees, with a force incomparably greater than a column of air of the same dimensions. A friend of mine at Cambridge, learned in philosophy, expresses the same mean opinion of a subtile medium; and thinks that, if admitted, it would not lessen the difficulties in philosophy. But Newton certainly did not reason in this manner: he thought, that gravity, with the impulse of a subtile medium, was a lesser difficulty in philosophy, than gravity without impulse: why, else, did he propose the former to supply the defects which had been objected to the latter? It is asked, whether it is easier to conceive a medium of so great rarity and elasticity diffused through all the planetary regions, than to conceive gravity without impulse? I must say, I think it is; because it will always be easier to conceive gravity with impulse, than gravity without it, even under all the disadvantages of that rarity in the medium, which it is now no longer necessary to suppose. But to these disadvantages it is added, that if we introduce the agency of one subtile medium into nature,

we must account for the power of that one, by multiplying other subtile matters without end. But the consequence is not necessary: for, if we keep within the bounds of nature and experiment, the proper province of physical disquisition, we shall soon come to a *ne plus ultra*. Thus, for example—a barrel of gun-powder blows a house up; and we find that gun-powder is a solid composition of nitre, sulphur and charcoal. How must we account for its effect? If we go beyond the solid matters of the composition, the minerals and the charcoal, shall we be obliged to multiply subtile matters without end? Surely there can be no occasion for this. Accordingly we find, when we examine farther, that the explosive force of gun-powder is from a blast of air in the nitre, expanded by fire in the sulphur; and that these are more suddenly kindled and opened by the mediation of charcoal. Thus we understand of gun-powder what philosophy inquires after: we discover, that its force is no quality of the solid materials; but that these comprehend quiescent air, excited to action, and expanded by fire. Gun-powder, with fire and air to give it force, is to me a much lesser difficulty in philosophy, as well as a

more

more satisfactory object to contemplate, than gun-powder with an immaterial repulsive virtue, that is, with an intangible soul in charcoal and minerals. And thus, by parity of reason, we must think, that in all departments of Nature, an effect with an impelling cause is a lesser difficulty than motion without impulse. I see no reason for inventing other subtile matters in succession without end, to account for the motions of the first. When I get to the subtile matter of fire, it is not requisite that I should go farther. If you should ask me, what gives this force to fire? I must answer the question by another; what makes the sun shine? What but the power of the Creator, for whose pleasure all things were created, and to whose laws all Nature is obedient? Philosophy searches after his instruments; Theology asserts his power; but Human Wisdom will never be able to settle the mode of its influence.

What I have hitherto said, will, I hope, be sufficient to give an idea of the object, the matter, and the argument, of that introductory publication, by which I endeavoured to remove the first of my difficulties, the supposed demonstration of an unmechanical constitution of Nature, by our excel-

-lent Newton; whose demonstrations, so far as they extend, no man can oppose, without being justly suspected of ignorance or presumption.

Great as my first difficulty might appear, I thought my second greater; and I found it so: because we know what is required of us when we are answering an argument; but no man can tell when he shall have satisfied a blind suspicion. All I can say is this: that if it should have been my lot to suffer under any false imputations, as many better men have done before me; and if I have been suspected of being led by incompetent authority into any opinions, either unprofitable or indefensible; the work I now offer must be my answer. This second book will shew what I had in view when I published the first. It will shew, that in every subject I treat of, I take my own ground, and work upon it in my own manner. It will shew, that I use every writer so far as he can assist me, while I take part with none. Many have been the commentators on philosophy, and none in the world so happy and successful in every part of it as those of our own country: *plures una gens eximios tulit in quocunque genere, quam ceteræ terræ:* but still,

still, NATURE is the text; and where there is difference of opinion, and authority seems to be against me, then I must plead that text, as a good protestant pleads his Bible.

The subjects I treat of are, the Elements of the World, their natures, properties, powers, and effects; which are the genuine objects of physiological inquiry, and open to us so large a fund of entertainment and improvement, that the sagacity of a Newton, if he were to live a thousand years, would never be able to exhaust it. It will be concluded, and very justly, that, in the prosecution of this study, I have been much indebted to the learned collections and discoveries of the Royal Society, of which I have the honour to be a member. I ought likewise to own, that, before I entered upon the business of experimenting for myself, I derived much information from the useful and extensive lectures on philosophical chemistry, by the late Dr. Alcock, in the University of Oxford: I should have been happy if he had lived to receive this testimony of my gratitude. A few select memoirs of his life were published in the last year, which cannot be perused with indifference by those who knew him, and were interested in the transactions

of his time.—But now it will be proper to say something of the manner in which I have treated the subjects of the present volume.

There are four distinct forms of Philosophy—mythological, systematical, experimental, and sacred; all of which must be applied to, as sources of information, by those who wish to understand the science of Natural Philosophy in its proper extent; as I have endeavoured to do, that I might place my work upon a broader foundation, and render it more generally useful.

The MYTHOLOGICAL form of philosophy is to be found in the theology of the Heathen priests, poets and philosophers. Their deity was the visible system of Nature; and their particular divinities, male and female, were the separate powers, agents and operations of the world. They supposed Nature to be eternal and self-moved, and sensible of men's words and actions; therefore they fell into the custom of representing Natural Philosophy under the mystical form of religious fable. True and rational Philosophy undertakes to make plain the wonders of Nature: but the mythologic form was invented to turn plain things into wonders, and give them an oracular dignity, to preserve them from

from the contempt of the vulgar. They who had no spiritual mysteries, or believed none, converted Natural Philosophy into mystery, and gave it the air of a divine revelation. The mysteries of the Hebrews related to a Theocracy, that is, to the intercourse of God with man: the mysteries of the Heathens to Physiocracy; for such we may call that constitution of the world, which gives the supreme government to the powers of Nature itself. I could illustrate what I here advance, by multiplying testimonies from writers of all ages; but this is occasionally done in the work itself. A fashion prevailed in the last century, of converting the fables of Gentilism into true history, on a supposition that they all took their rise from events related in the Scripture. In this attempt Bochart and Huet were leaders, and the erudition expended in it was immense, without any sensible benefit to the Christian, or the learned world. Lord Bacon, who is generally to be trusted in his ideas of literature, has some excellent observations on the fables of the ancients, and applies them for the most part according to their true physical intention: but he intermixes rather more of the moral than was intended by the fabrica-

tors of mythological mysteries. I have been more attentive to this sort of learning with a view to the younger scholars, whose interest I have had much at heart for several years. For their sakes I have taken occasion to introduce the subjects of philosophy, as they were conceived, and are referred to by writers of antiquity among the Greeks and Romans; to prove and explain how their mythology was a symbolical representation of the ways of Nature: by right understanding of which, their views in classical literature will be extended, and their reading made more profitable and agreeable.

The SYSTEMATICAL form of philosophy, is that which begins with laying down laws and principles to account for the phenomena of Nature, and treats Natural Philosophy as a science reducible throughout to certain rules. Of this sort was that which prevailed for so many ages in the schools, and was derived from Aristotle, and his commentators. It knew some things truly, and had a form of knowledge for all the rest; but it was nothing more than a form, so long as it explained things by certain terms which themselves wanted an explanation, and expressed nothing when considered as powers

of

of Nature. As some physicians have attempted to extend the efficacy of one particular medicine to the cure of all distempers; so have philosophers been tempted to assume some partial affection of Nature, and suppose it universal; while, in order to make it such, they must pervert things in a strange manner, and be guilty of many absurdities. A man may be a giant in his talents; but if he is contending for a system, he will occasionally argue like a child. Such was the error of Gilbert, an English philosopher, of Colchester, who flourished above two hundred years ago. He had studied magnetism with great attention, and was so filled up with it, that he could see nothing in the whole universe but magnetism. He made the globe of the earth a load-stone, solid to the centre; and supposed that a magnetical power in the sun was sufficient to account for the motions of the planets. And then after all, he accounted for the effect of the load-stone from an immaterial act of its form; to countenance which, he was diligent in searching for other like examples of incorporeal attraction. His doctrine was afterwards taken up by Kepler, who ascribed to the body of the sun an attractive power on one

one side, and a repulsive power on the other; a friendly and an unfriendly side, by both of which in their turns he was supposed to act upon the planets. The cause of magnetism being invisible, it was pronounced to be incorporeal; and all other instances of attraction were accounted for from a vigour impressed on the parts of matter, by which it could act without contact. If such a vigour really were in matter, what would become of the *vis inertiæ?* for matter cannot be both inert and vigorous at the same time. If spiritual vigour in solid bodies is substituted for mechanical impulse, it were vain to inquire after impelling fluids. This doctrine of impressed vigour in solids, unphilosophical and incredible as it is, was much in vogue in the beginning of the last century, on the credit of Gilbert; and I find it maintained by one of the first scholars in the world, who calls it "a magnetical vigour impressed by the Maker upon the whole frame;" delivering it *ex cathedra,* as a principle too well established to admit of any dispute*.

Kepler derived the revolution of the planets from the rotatory motion of the sun; but

* See the Works of Mr. J. Gregory. Edit. iv. p. 56.

but held that it took place very slowly from the natural *inertia* of the matter in the planets *. Descartes improved upon this: he added to the rotation of the sun a vertical motion in the fluid matter of the heavens; and maintained that this matter preserves the motion once impressed upon it, because all matter in itself is indifferent to rest or motion. The Newtonian system, which succeeded the Cartesian, and has taken place of it in all parts of Europe, adopted Descartes's law, and added to it the powers of attraction and repulsion as first principles; but with a reserve for the agency of a subtile medium in all departments of nature; the existence of which Newton himself allowed, but made no use of it in his Philosophy, for want of a sufficient number of experiments.

Experimental Philosophy deduces the properties of bodies from actual trials; reasoning first by analysis, and thence by composition. It has an advantage in being more nearly allied to Natural History than the systematic forms: for, as that is the best Moral Philosophy which is built on the real History of Man, so that must always be the best

* Kepl. Epil. Astron. lib. iv. p. 520.

best Natural Philosophy which is built upon the History of Nature. It is in Philosophy as in other things: experience is the greatest of all masters; and if it does not teach us something in Philosophy, this can only happen because we had been falsely taught before. The alchemist began his labours with this persuasion, that nature intended all metals for gold; and wanted nothing but the assistance of art to carry on the operation to its due effect, in all those instances where nature itself had miscarried: therefore, his experiments never gave him any light: he paid dearer for wit than most men, and never found it at last.

Lord Bacon was the first who attempted to rescue the learned from the bondage of system, and recall them from abstract reasonings to experiments. He threw out his Natural History in the form of a loose indigested collection of facts, to excite the public curiosity; as knowing that a farther inquiry, upon the same ground of actual observation, would naturally tend to take men off from their beloved notions and theories, to examine the real constitution of the world. All the late discoveries in Electricity, which have opened an entire new field in Philosophy,

have

have arisen from facts, to which the experimenters themselves were not led by any previous train of reasoning, but conducted by accident. Experimental Philosophy shews us, that certain effects are produced under such particular circumstances, which must be minutely attended to. Systematical Philosophy undertakes to shew *why* they are produced; and from some known effects deduces many others of the same kind. But with all this, there are few practitioners who are not attached by education or affection to some system, so that they will speak for an experiment, instead of permitting it to speak for itself. Having obtained the knowledge of some things, they wish not to be ignorant of any. But he is the happiest practitioner, who has any general scheme, to which the several parts of nature, when examined, will give a general testimony: and this, I think, is the case with that scheme of the Agency of the Elements, which I have endeavoured to cultivate and exhibit in this work, though I have not had occasion to carry it so far in this volume as I apprehend it will go when duly applied.

The Philosophers of Europe have now been making experiments professedly, and with every

every possible advantage, for above an hundred years: and it would be hard indeed, if from so much matter, collected with so much success, and illustrated with so much learning, no certain principles could be ascertained in the science of Physics. While I have been musing with myself on the improved state of Experimental Philosophy, I have often indulged a wish that I could exhibit to the wise men and heroes of ancient times, some of those wonderful improvements which are now so familiar to us, but were totally unknown to them. I would give to Aristotle the electrical shock; I would carry Alexander to see the experiments upon the Warren at Woolwich, together with all the evolutions and firings of a modern battalion; I would shew to Julius Cæsar, the invader of Britain, an English man of war; and to Archimedes a fire-engine, and a reflecting telescope. But here, as in other subjects of human attention, so in Philosophy, though we are under all these advantages, we are still carried away by an insatiable thirst after novelty: so true is the reflection of Seneca, *naturale est magis nova quam magna mirari;* we neglect what is great, to hunt after something that is new, that we may attract the admiration of the

public. We have a strange propensity to be looking either before us or behind us for variety, instead of cultivating the fruitful spot we stand upon. If we are already in possession of many great things, reason demands that we should be making our use of them, rather than be searching for novelties, which may be either of little value, or the same for substance with what is already known. I have, therefore, preferred the profits of culture to the pleasures of the chace; and would rather pass for a labourer than a sportsman upon philosophical ground; though I have reason to think many things new will occur to the reader, if he has the patience to look for them; and that the new things he will meet with, are such as will lead to a new train of experiments. A vain desire of accounting for all experiments, is an error I have endeavoured to avoid. Many phenomena in nature being unaccountable, we must sometimes be humble enough to admire what we cannot perfectly understand; as we survey the ocean with wonder and pleasure, though we cannot see to the bottom of it. After all the researches I have been able to make, I am still at a loss for the *physical* principle of musical consonance.

By

By SACRED Philosophy I understand that account of the generation of the world, and its present economy, which is revealed in the Scripture; not with the design of sending us to school, to learn Philosophy as a science; but with a view to the interests of religion, and therefore so far only as religion is concerned. The three great ends for which Nature is referred to in the Bible, are, first, to guard men from error; secondly, to open their understandings, by explaining spiritual truth from natural imagery; and thirdly, to inspire them with sentiments of devotion: and all this is generally done in concise language, as there is no room in that book for superfluous words. The History of the Formation and Constitution of the World is such as was sufficient to guard the Hebrews from the dangerous and profane doctrines of the Gentiles, who conspired universally to deify nature; to confound the Creator with his works; and to give to the world itself that adoration which is due only to the Maker of it. It therefore asserts and sets forth the power of the true God; the Maker of heaven and earth, and describes the natural dominion of the elements as dependent on the power of the Creator: that the sun, the

moon,

moon, and the host of heaven, observe the law they received from him in the beginning of the world: of which subordination and dependence the heathens had lost the knowledge, through the affectation of philosophical wisdom, till at length Nature itself took the place of the Creator; the substance of the elements was confounded with the substance of the Deity; the subtile matter of fire was held to be the soul of the world; the powers of the heaven and the earth became so many distinct divinities, and the history of their operations was converted into a religious mystery, such as we find every where in the occult doctrines of the Pagan Mythology, of which I have given so many examples in the following Discourses, that I trust that matter will no longer be doubtful; and it behoves us not to be unmindful of it. Late discoveries have again filled the world with matter, and revived the knowledge of those powers which the Heathens knew and worshipped. A vacuum is, or will be, forgotten; and the elements are likely to be restored, as of old, to their proper offices in nature. I have long foreseen (or feared I did) that whensoever this should come to pass, the light of Christianity,

tianity, with all the warnings and threatenings of the Scripture, would scarcely be found sufficient to secure us from relapsing into the ancient error, and taking once more the elements themselves for the gods that govern the world, ascribing intellectual power to organised matter, and smothering the distinction between body and spirit, which is the philosophy of *Materialism*; an unhappy system, which has always had its advocates, but can recommend itself only to the half-learned, inflated with the vanity of false wisdom, and destitute of the principle which the Scripture calls by the name of FAITH. In this plan I have no share: and it is part of the design of this work to guard the learned against it, and point out a more excellent way.

The second use of Sacred Philosophy is to open the understanding, and enlarge the conceptions of the mind, by giving it a prospect of both worlds; of the one from the other; of the invisible from the visible: for, as all our ideas enter by the senses, we have no way of conceiving the objects of faith, but from the objects of sense. The powers of Nature are symbolical of the powers of the Deity, and are applied in that capacity

city in numberless passages of the sacred writings; their operations are explanatory of the benefits we derive from him, and he who studies nature with a view to this particular use of it, and wishes to excel in Theology, will find a treasure opened to him which cannot easily be exhausted, and which, after long and frequent meditation, is to my mind one of the most valuable secrets in divine literature.

The third and last use of Sacred Philosophy, is to inspire us with devotion; and for this end Nature is described to us in such terms as display the wisdom of the Creator in ordaining, his power in effecting, and his goodness in administering all things, to the perfection, beauty, and grandeur of the world, and the happiness of all his creatures. With other philosophy we may live, and traffic, and amuse ourselves; but this is the philosophy with which a good man would wish to die. Of all these four different forms of Philosophy, the Mythological, the Systematical, the Experimental, and the Sacred, I have taken advantage, as I thought it would best promote the general design of my work.

Every author, if he could choose his readers,

ers, would wish to have them properly disposed to enter into the spirit of his undertaking: and I must observe there are other qualifications in readers, besides that of sufficiency in Literature, without which I can hope for no success. And first I must expect, that when the reader takes this book into his hand, he is well affected to its subject, and knows what it is to delight himself in the researches either of Natural Philosophy, or Natural History; without which I shall be holding up a spectacle to those who have no eyes to regard it. Curiosity then, and affection to the subject, are the first qualifications I wish to meet with: to which I would add some acquaintance with Arithmetic and Geometry. The mathematical learning of my reader cannot be too much, if it is joined to natural and experimental knowledge. Such a reader will look upon my book, as the sun looks upon the earth, to fetch out of it something more than appears, and raise a plant from a latent seed. But a very little mathematical learning will be more than enough, if it should unfortunately have infused the pedantry and emptiness which are found in some scholars of that class, who see nothing of the world but upon paper, and

think

think that with the knowledge of a few geometrical lines and abstract theorems, they have all that is essential in Philosophy, and are complete judges in the science. I have the satisfaction to know beforehand, that I shall have some readers who are adorned by nature and education with all the endowments I can wish for. There may be others as happily qualified, of whom I have no knowledge; and my book may find those whom I shall never see.

To those who think they have no concern with Philosophy as a matter out of their reach, I can assure them, I have but rarely attempted to go where persons of common learning, with proper attention, will not be able to follow me. Some of the Discourses are familiar and easy, from the nature of their subject: others are made so, as much as the case would admit, as being intended partly for the instruction of beginners, and actually applied to that purpose in some private lectures. The Discourse *on Motion* is necessarily abstruse in some parts of its argument, and cannot be well understood without an acquaintance with the common systematic forms of Philosophy, and the state of it in the last and present age: though, I appre-

hend, some hints I have given in this Introduction will help to make it easier. That *on Fossils* will be less useful, when the bodies referred to are not at hand: but this defect I have in some measure supplied, by introducing several figures of fossil bodies into the plates. The Discourse *on Music* requires some knowledge of the composition and resolution of ratios: it goes farther than I intended at first to carry it; and in some parts of it, a practical as well as a theoretical knowledge of the science is necessary: though it has many curious facts throughout, which, if they should demand a little more attention than ordinary, no philosophical reader who bestows that attention will repent of it. As I have taken an unbeaten track in the greater part of this book, I must warn the reader, that he will meet with some things which will appear strange to him, only because they are new, or, if old, but little thought of; which, on farther examination, and by comparison with other new things, will appear in a very different light. Things remote from common observation are at first indistinctly seen, like the remote objects in a prospect. We are in doubt whether they are hills or clouds which appear in the skirts of

of the horizon; but when we draw near to them, we find they are no vapours, but firm land, fit for culture and inhabitation.

Some misunderstandings may arise from inexperience; others from prejudice and disaffection. It is our great misfortune in this country, that we are so much inclined to party and faction upon every occasion. In Religion we are broken into sects, and disturbed with fanaticism in various shapes. In Politics we have parties, whose opposite views weaken the force of the strongest kingdom in Europe, and endanger the vitals of the constitution. And even in Philosophy, where nothing but candour and serenity should prevail, we are still subject to an intolerant spirit, which either absolutely hinders the advancement of science, or obliges it to run in one narrow channel. From the observations I have been able to make on mankind, I find them always more intolerant for error than for truth, which is great without the aids of worldly power or policy, and will prevail in the end by its own strength.

Hitherto I have been informing my reader what he is to expect: I must now tell him what he is not to expect. The nature of my work would seldom admit of an histori-

cal account of experiments. When they are delivered in detail, they take up much room, and if wantonly amplified, are more like the history of a man's own self, than a treatise upon Philosophy. The result of any trial is generally very short, and its doctrine is more to my purpose than its history; which, if the experiment is common, is to be met with in writers who have pursued a different plan. It is possible I may have carried this reserve too far; and I am apprehensive I shall be suspected of inaccuracy, because I have so studiously avoided minute descriptions. Having much matter to offer, and of various sorts, and having promised to confine myself to the compass of two volumes in quarto, I am under the necessity of compressing my matter into as small a compass as I conveniently can. The description of the machine to shew the force and heat of burning fire, would have been thrice as long as it is, if it had extended minutely to all particulars: but I did not mean to write as a mechanic; I have contented myself frequently with throwing out a general truth, leaving others to correct it with proper distinctions. Thus, in explaining the consonance of musical strings, I have said that the

vibrations

vibrations of the same pendulum compared among themselves, are isochronous; which is not true, except in small arcs of a circle, not sensibly differing from the arcs of a cycloid; but it is true so far as I have occasion for it, because the ordinary vibrations of musical strings are in exceeding small arcs, and it would have carried me out to a subject not before me, if I had distinguished more accurately.

To some, my plan may appear defective, because it does not abound with diagrams and demonstrations: but in these discourses I have little concern with that mixt Philosophy, which has been so well and so copiously treated of in several modern systems of great merit: and I have reason to believe that the public will be gratified with the best work of that kind by an ingenious mathematician of the university of Cambridge, who is qualified in every respect to answer their expectations. My work is of a more humble and popular nature; it is properly *physiological*, and its demonstrations are from facts; a sort of reasoning, which, if inferior on some occasions to the geometrical, is yet unexceptionable in Philosophy, and best accommodated to the capacities of all sorts of

readers.

readers. Mathematical demonstration, when applied to the properties and powers of matter, partakes of uncertainty, from our imperfect knowledge of the subject to which it is applied; and it has been extended injudiciously and affectedly to subjects where it has no place; for some have taught Divinity, and others have administered Medicines, upon mathematical principles. When Mr. Robins made his experiments on the resistance of the air to bodies in motion, Sir Isaac Newton had demonstrated that this resistance was as the square of the velocity; and it was reasonable to believe that the demonstration was universal: but when experiments were carried on to very high velocities, the rule failed entirely, and another took place, never till then suspected. As bodies lose their motion from the resistance of a fluid, it was supposed demonstrable, from thence, that a Vacuum is necessary to motion; but the contrary appears from other experiments, and the demonstration is but partial. Muschenbroek demonstrates, from Hydrostatics, that all bodies would be at rest in a fluid æther capable of occupying their pores, because a body of the same specific gravity with water is at rest in water; whence he concludes

concludes there can be no such æther. But if we begin the other way, and shew there actually is an æther in the pores of bodies, then it is found that the demonstration does not hold; and that the author, in stating the case, did not follow nature. Men can always prove with great ease what they already believe, or wish to be true. Pure Mathematics yield absolute demonstration; but when they are mixed with physical suppositions, then the demonstrations are conditional at best, and may be absolutely false. It is dangerous to call such mixt reasonings by the name of demonstrations; because they may exclude all farther inquiry by experiment; and they may likewise discourage the studies of some readers, who, under a persuasion that all philosophy lies deeply intrenched and fortified against common understandings, give up the whole science in despair. But there is a vast field open to all persons of a liberal education, wherein they may employ their minds with pleasure and profit, free from those terrors which stop the progress of many students. The Astronomer, the Navigator, the Engineer, must be Mathematicians; and it will be good for the

Philosopher

Philosopher if he is so too: but the properties of the elements are opened to us in a great measure by the experiments of Chemistry: Electricity has but little to do with calculation; and the philosophy of the three kingdoms, of plants, animals, and fossils, all full of wonders, may be treated of without the *formulæ* of Algebra.

Life is so short, and knowledge comes so slowly to man in this mortal state, that nothing should be represented under an obscure form, which is capable of a plain one. If obscurity is an art, any man may attain to it, and may soon render unsearchable that which is not worth finding. The proper end of every instructive composition is to illuminate: and the small taper, which gives us light to read by, is preferable to the blazing meteor of the sky, which raises our astonishment, but soon leaves us in darkness. Authors in all ages have been touched with the ambition of being mysterious; as if learning grew more honourable in proportion as it is less intelligible. This sentiment is so handsomely and judiciously expressed by a writer who has fallen in my way, that I shall place his words in the margin for an admonition

to

to the learned*. Instead of making difficult what is naturally easy, it is my desire, and has been my endeavour, to invent such a method as might render easy what is naturally difficult. In the style and manner of my work, I have rather proposed Seneca and the elder Pliny as my models, than the authors of Systematical Treatises, who are perhaps too cautious of departing from the natural dryness of their method. One author indeed has of late ventured to give a more liberal and classical turn to a philosophical discourse, the subject of which is nevertheless handled with mathematical exactness†.

Mathema-

* Dolendum vero jure meritoque est, quod ratio humana, etiam in hoc negotio, labem illam suam primordialem, fastum atque superbiam, pro lapide offensionis et fundamento lapsus sui habeat: dum simplicitatem perosa, nihil nisi speciosa, operosa, intricata, abstrusa, affectans: notiora vero, faciliora, singularia, despiciens: perverso ordine, fastigio adnitens, vel omnino inde excutitur, atque in inane decidit; vel clausa ibi omnia atque obsignata deprehendens, et interiora penetrare impos, ex superficialibus quibusdam, crassioribus, Phænomenis, fingit sibi potentias quasdam, difficillime quidem materiales, promptissime vero immateriales; e quibus hodierni illi insiti et concreati nisus et motus, Materiæ interni, et quæcunque illos possidens atque perficiens facultas, primum locum possident. STAHL. Specim. Becher, p. 234.

† *Doctrina Sonorum*, by the ingenious Mr. Hales of Dublin.

Mathematicians are wont to consider the elements so far only as they come under the idea of *quantity*: whereas the Science of Physics should consider them chiefly in their *qualities* and operations. Quantity is the body of Nature, and Quality is the soul of it. The part of Natural Philosophy which always seemed to me most useful and instructive, was the economy of the Elements, and the final causes of their effects; which, in some respects, have been admirably well treated of by Ray, Derham, Neiwentyt, and other excellent writers of that class. This sort of Philosophy may be thought less sublime, because it has less difficulty; but it may be of more general benefit than abstruse theories, which may do great honour to their authors, but lock up, even from persons of good learning, what they would be glad to partake of, according to their measure, in a more popular form.

Though I never advertised the conditions of this volume in the public papers, I gave my friends reason to expect, from my private proposals, that it would contain a Discourse on Electricity. This I reserved for the last; that while the other papers were in the press, I might take advantage of any thing new that

that should arise from others, or occur to myself, to render it more perfect. In the mean while, the volume grew to such a size, and the other discourses took up so much more room than my calculation had allowed, (I wish I may have under-rated them in every other respect) that to keep the volume within bounds, and to the proposed price, I am obliged either to reserve that piece for the other volume, or make a treatise of it by itself. To bring it into any tolerable compass for this present publication, I must have changed its form, and abridged my materials into titles and propositions; by doing which I should have disappointed my reader, and have been unjust to myself as well as to the subject. My plan receives such confirmation from the new lights of modern electricity, that I cannot say whether I should have been bold enough to have undertaken any part of it without that encouragement. This volume, however, contains nine separate Discourses, the number which my proposals promised: and as these carry us through the elements of fire, air, earth and water, the volume is so far a complete work by itself. Instead of a few paragraphs, which were all I intended to select on the philosophy of

musical sounds, and to introduce them into the Discourse upon Air; I have published the chief of my speculations on that subject, and made a separate discourse of it. I should have been tempted to add some farther considerations, had I seen the Discourse of the Spaniard, Feyjoo, upon Music, before my own was printed: but now I must refer the musical reader to it, not as a philosophical, but a sentimental piece. Had I been apprized of it in time, I would have mentioned the great Lord Keeper Guildford, as the father of Musical Philosophy in this country; who first started it in our Royal Society, and was followed by Matthews, Hook, Wallis, and Holder. He printed a Philosophical Essay on Music, which in those earlier days had great merit; and was himself a very skilful composer*. I might also have descended to a particular inquiry into the effects of music upon the passions, under the title of Pathology; and have shewn how the larger intervals elevate and expand the mind, while the lesser depress and contract it; on which there is much to be said; and the consideration of it, if I could be so happy as to represent

* See Roger North's Life of the Lord Keeper Guildford, p. 296.

represent it rightly, might regulate our taste, and prevent our sinking deeper, as we do daily, into that whining effeminate style, so abounding with accidentals, and half intervals; the present relish for which is not natural, but acquired, and I believe in a great measure imaginary; like the pleasure a man finds in gnawing the ends of his fingers, when he is fallen under the dominion of a vicious habit. New habits bring new inclinations; and a depraved taste will find itself happy with depraved music.

As wise and good men have always admitted a certain alliance between Philosophy and Divinity, and have pronounced, that Nature is but half studied till it enables us to contemplate the great objects of Religion with superior light; I have therefore endeavoured to lose no opportunity of turning natural knowledge to the illustration of Divine Truth, and the advancement of Virtue. This step will not recommend me to all readers; and yet I hope I shall stand in need of no apology for doing what may frequently be done by writers who are so inclined, without any violence to Natural Philosophy. Who amongst us can want to be convinced, in this age, that men versed in the study of

Nature have gone to unwarrantable lengths, and raised spiritual doctrines, not less absurd than dangerous, upon natural observations? So many strange things have happened from the abuse of Philosophy, that it would now be scarcely wonderful if a temple should be erected to the ÆTHER, the FATHER ALMIGHTY of the idolatrous Sages of antiquity*. One of the physicians of the late king, who was a friend to my studies, and for whose learning and virtues I had great esteem, would be asking me sometimes, what philosophy had to do with religion? But surely a Boyle or a Newton will answer that question

* *Tum* PATER OMNIPOTENS *fœcundis imbribus* ÆTHER. An institution, nearly approaching to this act of impiety, was set on foot about fifty or sixty years ago in this kingdom by a society of philosophical idolaters, who called themselves Pantheists, because they professed the worship of *All Nature* as their Deity. They had Mr. John Toland for their secretary and chaplain. Their Liturgy was in Latin, the copies of which are very scarce: I never saw more than one of them. An English translation was published in 1751; from which I will here extract a passage asserting the divinity of Etherial Fire.——"The Etherial "Fire; invironing all things, and therefore supreme:—the "Æther is a reviving fire—it rules all things, it disposes "all things—in it is soul, mind, prudence—This Fire is "Horace's

question for us. Besides, the use may be inferred from the abuse; and it has always been held lawful to learn wisdom of an enemy. Voltaire never failed to turn the little philosophy he was master of (which in his hands seemed to be a great deal) to the disadvantage of religion; that from his mole-hill of science he might lord it over Christian Truth, and bring Faith and Virtue into contempt with his readers; in which he has been too successful. Natural Philosophy has long been under some suspicion, either of being a false friend or a dangerous enemy to Revelation: and some good men, at the first establishment of the Royal Society, were apprehensive of ill effects from the institution; that it would bring into vogue a sort of empirical literature, which would puff men up with a vain conceit of wisdom; and farther,

 that

"Horace's *particle of divine breath*, and Virgil's *inwardly* "*nourishing spirit*—All things are comprised in an intelli-"gent Nature.—This force they call the soul of the world, "as also a mind, and perfect wisdom, and consequently "GOD." See p. 23, 24, 61. Vanini, the Italian philosopher, who was burned for an atheist, was very nearly of this opinion: his god was Nature. Some very learned and excellent remarks are made on this error by Mr. Boyle, in his Discourse on the vulgarly received notion of Nature. See section IV.

that experiments upon Nature would lead to experiments upon Religion, and so, in the issue, make way for Scepticism and Infidelity. In answer to which, the elegant apologist of the Society, Dr. Sprat, declared, that "if the design should in the least diminish the reverence that is due to the Doctrine of Jesus Christ, it were so far from deserving protection, that it ought to be abhorred by all the politic and prudent, as well as the devout part of Christendom." What he has added to prove the suspicion groundless, and injurious to true Philosophy, is much to the purpose, and worthy of consideration. It is not Philosophy, but the abuse of Philosophy, or the use of something falsely so called, the production of men's brains, not a sober observation of the works and ways of Nature, which is dangerous to Religion. The inquiry into the order of Nature and natural causes can never fail to be attended with a display of the Divine Wisdom: and as there is a certain analogy between the Divine Attributes, no man can be made averse to the Word of God by admiring his works, or raise objections against his Truth, from the study of his power and wisdom.

Dr. Grew, in his Anatomy of Plants, insists

sists well on this argument. "Nature," says he, "and the causes and reasons of things duly contemplated, naturally lead us unto God, and is one way of securing our veneration of him; giving us not only a general demonstration of his Being, but a particular one of most of the qualifications thereof—By the same means we have a greater assurance of the excellency of his sacred word: that he who hath done all things so transcendantly well, must needs speak as well as he hath done——We may as well deny what God hath made to be, as what he hath spoken to be true, because we understand not how——It is not therefore the knowledge of Nature, but they are the wanton fancies of men's minds, that dispose them either to forget God, or to think unduly of him*." So reasoned this worthy and learned member of the Royal Society: and every person of sound sense and literature will agree with him, that the true interpretation of Nature, whatever that may be, must be instrumental toward the confirmation of revealed truth.

To those who know the character and writings of the famous Roger Bacon, his example

* Grew's Anat. of Plants, book ii. p. 79, 80.

ple will occur on the present occasion. This first of English philosophers, with his profound skill in mechanics, optics, astronomy, and chemistry, which would make an honourable figure in the present age, was intitled to this praise also, that he made all his studies subservient to theology, and directed all his writings, as much as could be, to the glory of God. He had the highest regard for the Sacred Scriptures, and was persuaded that they contain the principles of all true science. He had a liberal way of considering things; not adhering servilely to his subject, but using all the sciences, of which he was master, to illustrate one another. But his chief concern at last was to turn all things to the advancement of Divinity. It is very unjust to speak of philosophy as if nothing had been known in the science till the last century; when in reality a scholar furnished with no materials whatsoever, but such as might be extracted from Friar Bacon's writings, would yet be a very considerable person, and entitled to no small degree of fame among the literati of the present age, with all its improvements. He would excel as a mathematician, experimentalist, physician, chemist, artist, astronomer, philosopher,

and

and divine*. This is the pattern which, if I were ambitious, I would wish to imitate; and we may adopt his manner and spirit without pretending to his genius, which few or none will ever inherit. It is not a little remarkable, that the great Lord Bacon, in all his philosophical writings, has never once mentioned the name of Friar Bacon, his namesake and predecessor in the same line of philosophical and universal learning, though he has frequently spoken of Gilbert's magnetic philosophy, and many other things far less considerable. This was observed to me by a learned nobleman, not less acquainted with Newton than with Bacon, who assured me he had been at the pains to examine all Lord Bacon's writings with this particular view.

Natural Philosophy is now a study so much in repute, that little need be added to explain the uses of it, especially as some observations to this purpose have occurred in what has already been said. To the Poet, the Orator, and particularly to the Divine, the knowledge of Nature is necessary; and,

 next

* See the Life of Roger Bacon in the Biographia Britannica.

next to the God of nature, Nature itself is the greatest object we have to contemplate. It helps greatly to furnish the mind with a store of imagery, that reason may be enabled to make the most of its powers, and that things too high, or too obscure, for the mind to conceive as they are in themselves, may be illustrated by means of their alliance to sensible objects. The Platonists were informed of this analogy, and excelled in making this use of Nature; but we, who have more light now, may succeed still better. In the business of life, natural knowledge is of essential service to physicians, chemists, gardeners, husbandmen, and artificers of every kind; many valuable secrets among manufacturers, being no other than philosophical experiments. Such persons may not only understand what is old, but strike out something new and useful, when philosophy has enabled them to see farther into the principles of their art, for all art is founded on Nature. Many remedies of diseases are purely philosophical; and their causes and theory are of philosophical consideration. Anatomy and the animal economy compose one of the chief branches of physi-

ology.

ology. No artificer can pursue his craft without seeing how necessary some of the elements are to assist him in his works; how insufficient manual labour would be without their concurrence; what great things are already done, and how many more may be, when they are farther understood and applied. It is a capital distinction between operations natural and artificial, that Nature penetrates, while Art stops at the surface. Hence, if we would work as Nature works, we must use the agents which Nature uses.

I have now, as I hope, fully explained the considerations which prevailed with me to write on Natural Philosophy; and I can sincerely affirm, that the work is rather a work of duty than of ostentation, to which if the reader is inclined to do justice, I must desire him to remember, that my whole scheme should be taken together, and that this book is but a part of it. When I first looked forward upon the plan, I had a very different idea from that which presents itself to me now I look back upon it. Had it appeared then as it does now, I should have left it for some better hand to execute; and were I to detain a work of so much difficulty, and

compre-

comprehending such a variety of subjects as will be found in it, till I could approve it, and be satisfied that I had done what I might and ought to have done, it would never come abroad. I must therefore hope to correct some things by farther examination, and shall never be ashamed to improve what I publish, by means of such hints as friendly information, or even hostile criticism itself, shall hereafter throw in my way. If some should neglect my philosophical writings, either on the just ground of their own superior knowledge, or from lower motives of vanity, envy, or interest; I know that every author must commit his works to the times in which he writes, whether they are favourable or adverse to his undertaking; and when he has launched his vessel, he must leave it to the chance of the wind and the weather. My mind, however, suggests to me, that this book will not be totally thrown aside and forgotten. That natural agency of the elements for which I have pleaded, and which I hope to carry farther, (however imperfectly,) is so reasonable, so striking, so intimately interwoven with the most agreeable and interesting parts of literature, that

it

it must, when it comes to be better understood, find friends and favourers either in this country or some other, with abilities to defend what shall have been rightly done in this great subject, and to improve it by their own more successful labours.

DISCOURSE I.

Of Matter, and the several Kinds of Bodies.

MATTER is that tangible substance which occupies space, and is subject to a variety of visible forms. It is either homogeneous or heterogeneous; that is, either simple or compound. There are, indeed, very few masses of matter that are perfectly simple. Many seem so, as the water of the sea, and the mould of the earth; but sea-water has a considerable mixture of salt in it, with other earthy and bituminous parts, which soon ferment when the sea-water is stagnant, and send forth a fœtid smell. The mould of the earth, how uniform soever it may appear by its colour, is made up of earth, oil, salt, watry, and metallic parts. Water may be rendered simple by distillation, and earth by burning; but absolute simplicity seems rarely to be found, except it be in the matter of light or fire.

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The first particles or principles of which matter is composed are *atoms*, those very small invisible elements of bodies which cannot be *cut* or *divided*, for such is the signification of the word *atom*. It has been a question, whether matter can be infinitely divided; that is, whether the parts of any given mass can be multiplied without end. The notion of an *atom* is against this; but sometimes we mean no more by an atom than those small particles, the figures of which are proper to the bodies composed by them, and which can never be changed so long as that body preserves its nature. Bodies may be very much changed in their form and outward appearance, while their component parts suffer no change. What can differ more from itself than the metal of lead, in its solid state, from the powder of red lead? Yet this powder will easily revert to its former condition of solid lead, when mixed over the fire with any oily or inflammable matter, which the chemists call *phlogiston*. Even the glass of lead, when ground with charcoal, and melted in the fire, will return again to its metallic form.

Matter is capable of many seeming transformations, but no real transmutations have ever

ever been discovered. Plants and animals are not transmuted from the matter of the earth by which they are nourished; because the matter proper for the nourishment of any particular vegetable will be exhausted by degrees from the soil, which could not happen if bodies received their growth from the transmutation of particles originally homogeneous. At their dissolution, both plants and animals return to the same sort of vegetable earth out of which they arose. An artificial analysis of their composition, as well as their own natural decay, shews them to be made up of such ingredients as the earth itself is, the particular nature of which belongs to another subject.

Constituent Parts of Bodies.

Atoms, understood in a grosser sense, as constituent parts of bodies, are distinguished by their figures; some of which are cubic, some in angular columns, some round, some acute or spiculated: the small grains of sea salt and of lead are cubic, nitre is hexangular, blood and oil are globular, corrosive sublimate spiculated, and antimony is in small filaments like needles. Where the

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discernible massules of bodies have any particular figure, it is natural to suppose that the indiscernible ones, out of which they are more intimately composed, may have the same, or a similar figure; and that the figure of the whole arises from the figure of the parts.

Many of the effects of bodies may be naturally derived from the configuration of their particles: as for example, the spiculated are sharp and corrosive, piercing and wounding the parts to which they are applied, while the globular are insipid and balsamic. Hence the spicular poisons, as antimony and sublimate, may be rendered inoffensive by sheathing their points in oil or wax. The powdered glass of antimony, by being *cerated*, that is, mixed with a proper quantity of melted bees-wax, becomes a gentle and healing medicine; though a single grain of the same powder, in its naked state, would vomit a strong man to death. Sulphur, which when cold is a brittle oil, has the same effect in sheathing the parts and checking the effects of corrosive medicines, such as the preparations of mercury and antimony. The solidity and fluidity of different bodies may depend in some measure on the figure of their particles,

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the globular composing fluids, which admit of a free motion among themselves, while the angular settle into solid bodies, whose parts are immoveable. But solidity and fluidity is also certainly owing to other causes, because the same mass will be fluid or solid under different circumstances. Water fixes into solid ice under a certain degree of cold; and gold or iron, with certain degrees of heat, may be made to flow like oil or water: whence it may be collected, that these different conditions depend rather on the state of that elementary matter which flows round about them, and is within their pores.

Divisibility of Matter.

The parts of matter may be divided from each other, without any limits which we are able to determine: we may therefore allow, that matter is indefinitely divisible; but if we should affirm it to be infinitely divisible, we shall have some monstrous absurdities to encounter. Suppose there are two masses of matter, A and B, and that B is equal to twice A; if the parts of both these masses are infinite in number, then one of these two consequences must follow, either that the less

less is equal to the greater, and so a part equal to the whole; or that we shall have two infinites, one of which is but a part of the other, which is contrary to all the ideas we have of infinity. So again, if the whole is finite, while the parts are infinite, it must follow, that the parts are greater than the whole; or, which comes to the same, that parts infinite in number will compose an whole that is finite. It is impossible to imagine the parts of matter so far divided but that number may be applied to measure them, because we can increase numbers in our imagination as fast and as far as we can divide the parts of matter; but hence it will follow, that the parts cannot be infinite, because this will infer the necessity of an infinite number, which is an absurdity, because it is a number to which you cannot add one.

Mathematicians are wont to illustrate their thoughts by lines, and their properties; and they sometimes give the name of demonstrations to their arguments, when they are nothing more than illustrations or diagrams, which express the mind of the illustrator, but prove nothing. According to the different lights in which a subject is considered, the application of different lines will lead to con-

trary conclusions. It would be easy enough to shew, on such principles, that a given quantity of matter is both finite and infinite; that it may be divided without end, and that there must necessarily be an end of the division. Therefore, it is safer on many occasions to be guided by reason, and the nature of things, at least in matters of argumentation, than by diagrams, which are applicable to contradictions, and may, indeed, be accommodated to any thing. It is also very dangerous to follow the conceptions of the imagination, which are often very deceitful, and lead us away from more rational parts of science, to wander about in barren regions, where there is no certain improvement. The imagination may suppose a series of musical sounds, in octaves, one above another, without end, and a stretched musical string upon a monochord may seem capable of perpetual bisection; but in fact, the ear is bewildered when sounds are continued but a few octaves above or below the middle pitch (𝅜) of the musical scale. Such speculations are of no use; and, when minutely pursued, serve only to deceive and perplex the understanding.

How far soever matter may be divisible in its own nature, we can conceive no idea of its

its composition, but as it consists of units. All substance is measured either by number or weight: number is made up of units, and weight is no practical measure, till some elements are fixed upon as the units of which all other weights are composed. We therefore find ourselves under the necessity of considering all matter as made up of atoms or units; and it is most reasonable to suppose, that all bodies, which are the same in kind, agree in the configuration of their smallest parts, and consist of elements rendered permanent and unchangeable by the express design of the Creator; otherwise, the world that now is might differ widely from that which was made in the beginning: the original properties of bodies would be lost, and new ones might arise without end, and without utility. "That nature (saith Sir "*Isaac Newton*) may be lasting, the changes "of corporeal things are to be placed only "in the various separations and associations, "and motions of those permanent particles; "compound bodies being apt to break, not "in the midst of solid particles, but where "those particles are laid together, and only "touch in a few points*."

Properties

* Newt. Opt. Q. 31.

Properties of Matter.

The atoms of all matter in general have the following properties: 1. *Hardness.* 2. *Impenetrability.* 3. *Resistance.* 4. *Mobility.*

When we speak of *hardness* as one of the properties of all atoms, we do not mean it in such a sense as when we compare one body with another, and say, this is hard in respect of that; but hardness absolute, such as cannot be altered or wrought upon by any violence from collision, attrition, or any other external force.

Impenetrability is a necessary consequence of the former property. By this it is meant, that two units of matter cannot exist at the same time in the same place; so long as the one retains its place, it must necessarily exclude the other. Bodies, however, may be understood to penetrate one another's dimensions so far as to be circumscribed by the same space; or, the same space may be understood to comprehend at the same time the parts of very different bodies. When copper and tin are melted together, the bulk of the copper is so little increased by the admixture of the tin, that the parts of the latter must

have found room to seat themselves within the pores of the former; and it is probably owing to this filling up of the pores, that the sound of the mass is so much improved, though the brittleness may have some share in the effect. If a vessel were to be filled with musquet balls, many interstitial spaces would be left, which might be filled with sand; and this also would leave its vacuities, which might be supplied with water: the water in like manner contains the particles of air; and air again contains the particles of a finer ether, which is every where expanded. On this principle the visible world is filled with matter: for if grosser bodies are excluded from any space, more subtile ones, which no art can exclude, will be present in it. It cannot be proved, or reasonably supposed, that there is any point of space within the limits of the solar system capable of admitting a particle of light, be it either within the pores of solid bodies, or in the free spaces of the heavens, but what hath at all times such a particle in it. How this is to be understood, and how it consists with the free motion of bodies, will be shewn hereafter, when we come to consider the nature and causes of motion.

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When we allow a principle of *resistance* to atoms, we do not mean it in such a sense as if they were made only to be inert, and stand in the way: for, by the constitution of the world, some are so far from resisting motion, that in fact they are already in motion, and are instrumental to the motion of others: but we mean only, that as they have no innate powers of motion in themselves, they must, in consequence of their impenetrability, resist any force that is applied to displace them. If we consider the fact of resistance as it now stands, it seems rather to take place from that certain determination which all the parts of matter are under, and in consequence of which they require a force to turn them out of that way which is appointed to them by the established laws of nature. How far any parcel of matter would resist, if it could be taken independent of the present frame of nature, and what force would be requisite in such a case to move any given quantity of matter in all directions indifferently, we cannot say, because we cannot place any matter in such a state to make the trial. As things now are, the actual resistance we find in matter being, *cæteris paribus*, in proportion to its weight, it seems to

be the necessary consequence of that effect which we call gravity: so that if any matter can be placed under such circumstances, as to be less affected by gravity, (which is the case with bodies floating in a liquor of the same specific gravity with themselves,) their resistance will be lessened; and if there be any subtile fluid not subject to the effect of gravity, such a fluid will have no sensible resistance at all.

Mobility in atoms is nothing more than a capacity of being moved by any external mechanical force applied to them; not that they are endued with any internal power of moving themselves. If we should say, that matter is by nature inert, and resisting, and indifferent to motion, and then should proceed to give the same matter a disposition to move without some external force, we should invest it at once with power and impotence, with sluggishness and activity, which cannot both be predicated of it without contradiction. The trumpet hath a capacity of sounding, but never till it is sounded: of itself it is dead and silent, and, as long as left to itself, must always remain so. Matter, in like manner, hath a capacity of motion, not an ability to move; neither doth any matter

act but so far as it is acted upon. Let us imagine the present laws of nature suspended, and all matter annihilated, except one single atom; we all confess that this atom can have no inclination to move one way rather than another, but must remain absolutely at rest; and all this from its own inert nature. If we introduce another atom at a distance from the former, they will both be at rest; for the properties of matter are not changed by having two atoms instead of one. Lay two trumpets near each other, and you will have no more sound than from one, till you apply some force which is not natural to either. To invest matter with any innate powers or self-inclinations to motion, call them by what names you please, is as contrary to the real nature of matter, as to suppose that all trumpets are born with lips and lungs, and breath of their own. A stringed instrument has the capacity of sending forth all possible harmony; but it must first be acted upon, either by the vibratory motion of the air (as in the Æolian harp), or by the hand of the master immediately, or by the interposition of a series of machinery. Such, then, is the *mobility* of matter; it is a capacity of being moved and acted upon, but no motive

motive faculty of any kind within itself; to allow which, would be to make the world an animal, and the parts of it all animated, as the Stoics of old did*. If we affirm matter to be inert, and desire to be consistent, we must banish from philosophy all such things as *vis attractrix*, *potentia quæ inest materiæ*, *propriæ particularum vires*, *corpora trahentia*, *materiæ vis superaddita*, *materia attractiva*, &c. &c.

Properties of Bodies.

The parts of all matter whatsoever have the four properties above described, which four may, with no great impropriety, be reduced to the two properties of hardness and mobility; and it cannot be demonstrated that they have any other besides those we have already explained. When the atoms of matter are assembled into masses, and form concrete bodies, many new properties arise from their different associations. The first

* This notion was revived of late years by Dr. Clayton, Author of an Essay on Spirit. He resolved all attractions and repulsions into an animation of matter, and supposed them to be the work of certain souls and spirits resident in all natural bodies, and commissioned to act in the several departments of nature.

first of which is *divisibility;* for whatever hath been accidentally joined since the first establishment of things in their unchangeable principles at the creation, by some means or other may be separated. No concrete body has ever yet been found, which can resist the force of art. Either percussion, tension, trituration, the action of a dissolving fluid, which the chemists call a *menstruum*, and, above all, the active power of fire, will disunite the particles of all concrete bodies.

There are many combinations or compositions of the primary parts of bodies into secondary masses, and subsequent decompositions of the same in the ordinary course of nature, by which the condition of bodies is very much affected. The fluid parts of olive oil are assembled into globular masses with a certain degree of cold, till with the increasing cold the whole becomes congealed; and the same are decomposed again with heat, and refined and subdivided to such a degree by a greater heat, that they will penetrate the pores even of iron itself. The particles of serum are associated into globules of red blood, and the same are relaxed again and separated when the blood is in a

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broken watry state. These combinations and separations, or compositions and decompositions, are to be found in other parts of nature, and, when admitted in their proper extent, may help us to account for some things not very conceivable without them. Experiments shew, that even air and fire are capable of fixity, which is no other than an association of their primary parts into a quiescent state; and strange effects arise from their decomposition, when they are expanded again into their natural state, and become volatile. All the changes wrought upon bodies by the operations of chemistry are reducible to these two, of uniting and separating the parts of bodies; and infinite are the productions of art which arise from these two principles: but here it is to be understood, that these combinations take place, not only between atoms which are the same in kind, but between the constituent elements of different substances, and then an infinite variety is the result.

Art will divide bodies into a greater or lesser number of parts, according to the different constitutions of the bodies so divided. Such is the subtilty of gold, that twelve millions of its particles may be demonstrated to be

be comprehended in the length of one inch; so that if an inch of length be supposed to contain an hundred grains of sand, each grain will take up as much room as an hundred and twenty thousand particles of gold; yet this exquisite division cannot be supposed to have carried us up to the first elements of which gold is composed. Thus far its subtilty may be pursued by inspection with a microscope. The method of dividing it practically into its smallest parts, is to dissolve and incorporate it by admixture with some other matter. A single grain of gold mixt with a pound of quicksilver will be so intimately dissolved as to be distributed equally through the whole mass; and on this principle other metals are overlaid with gold. The solution being rubbed over the surface, and the mercurial part made to evaporate by fire, the particles of gold are left behind in a very fine coat, inconceivably thin, and perfectly covering the whole face of the metal. If a plate of brass or copper be washed over lightly with aqua-fortis in which pure silver has been dissolved, the atoms of silver being separated from the fluid, and precipitated by this application, give a new face to the whole plate, which

will last for many years. No manual operation could possibly divide the parts of gold and silver to such a degree of minuteness. A very small quantity of oil of vitriol, mixed with a very large quantity of water, will be so equally distributed as to give a sensible acidity to every drop of the water. As to odours, which arise copiously from bodies without diminishing their weight, they may be occasioned not by an actual diffusion of the substance, but by the modification of a more subtile spirit, which is continually passing through their pores: as an infinite number of parts evaporate from a burning fire which were never resident in the fuel, but pass through it by means of the continual accession of other matter. Camphire will indeed consume in substance as it gives its odour, till the whole mass is volatilized by the air and vanishes away.

Ductility is another property peculiar to some bodies, by which it is meant, that they may be extended in length or breadth without a separation of the parts. If the matter is soft and inclining to be fluid, then this property is called *plasticity:* if it is capable of being flattened and spread abroad by the strokes of a hammer, then it is termed *malleability.*

leability. Gold has this last property in a degree far beyond all other substances. Lead, copper, and silver, are also both malleable and ductile: wire is drawn out very fine both from copper and silver: but of gold it is affirmed by *Boerhaave*, that a single grain of it may be stretched under a hammer till it is big enough to cover a house.

Opposite to ductility is *brittleness*. Matter which has this quality, consists of parts so posited that they will not be drawn about, but fly asunder when any violence is offered to them. There is a metal which in weight and colour very much resembles gold, but, being incurably brittle, cannot be applied to any of the purposes of gold. Some other metals in their native state are apt to be very brittle and unfit for use, till they are cleared by art of their sulphur, that cold brittle oil, which is mixed with them in too large a proportion. This is often the case with iron, to the ore of which they had some calcarious or alkaline matter to absorb the sulphur, and render the metal malleable. It may seem strange that sulphur, which may be rendered so fluid by heat, should be a cause of brittleness: but when it has only such an heat as will soften it, it has no ductility any more than

than sand; and, when cold, will crack and fly either with friction or the application of a very gentle heat. Of all matter glass is the most brittle: and it is observed of this and other substances which have the like brittleness, that they generally break with a polished surface superior to any which art can give them, as pitch, rosin, sealing-wax: because their parts are united only by simple contact, not by insertion or implication, as bodies which are tough and fibrous.

Many substances, which are brittle in their ordinary state, may be rendered very ductile by heat; pitch and wax by a very slight degree, rosin by a greater, and glass itself by the heat of a furnace, when it may be extended to any degree by a blast of the breath, and molded into any kind of figure. If it is figured when cold, the parts are abraded by grinding it with water and some hard powder, as sand, emery, or the powder of diamonds, which frets and wears it away.

Elasticity is that property of bodies by which their parts are restored again to their natural figure and position, when they have been driven or pressed out of it by any violence. A sponge squeezed into a smaller compass, will be expanded instantly to its

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former bulk when the force is withdrawn. A ball of ivory laid upon a polished slab of marble, will touch it but in a few points: but if it be dropped from any height, and means are used, either by oiling or wetting the marble, to mark the contact exactly, it will be found to make a broad round spot: which shews that the parts were pressed inwards by the fall, and are immediately restored again to their proper position. When we press a bladder blown up with air, we say it is elastic; but we know that the elasticity is not in the bladder, but in the medium which it contains within it. And the same is true in other cases: elasticity is not in the solid parts of bodies, but in the fluid within their pores; and therefore, as the condition of this fluid is altered, bodies may have their elasticity, and lose it, and acquire it again. The spring of a watch, by the application of fire, may be made as brittle as glass, or straitened, or bended backwards and made to exert its spring the contrary way. The disposition or construction of the solid parts may in many cases contribute to the effect of elasticity, though it is not to be imputed to any power in the parts themselves.

Transparency and *opacity* are other proper-

ties of matter, which respect the passage of the rays of light through their substance.—It is evident to reason, that the atoms or units of which bodies are composed, being impenetrable in their nature, must be impervious to the rays of light, how subtile and powerful soever the light may be in its own nature. The light therefore, in its passage, must penetrate the porous vacuities; and it will be differently affected in its passage, as the units are differently figured and differently posited in regard to their pores. The rays of that uniform white light by which all objects are rendered visible proceed in strait lines: but when these rays are broken and dissipated into a variety of directions, they no longer affect us with the sense of light. When the interstitial vacuities of bodies are so disposed that the light can preserve its rectilinear course through them, such bodies appear luminous throughout, and are visible in their internal substance: but when their constitution is such as will not allow a free passage to the light, they are then visible only by those rays which are reflected from their surface, and their internal substance is opaque or dark.

Bodies not transparent in their ordinary

state, may be rendered so, either by relaxing their parts with heat, so that the light may pass through them more easily; or by giving some new direction, together with an additional force, to the matter of light. Mr. Hawksbee, one of the first modern electricians, was very much surprised to find that the sealing-wax and the pitch within-side a glass globe (that is, applied as an inner coating to one hemisphere of the globe) became so transparent when the glass was whirled about and rubbed with the hand, that the fingers might plainly be seen on the other side through the coating*. Oil is condensed when cold into a sort of globules impervious to the light, and becomes as opaque as a solid lump of suet: but when these globules are dissolved, and opened by the action of fire, the oil not only becomes transparent, but appears as bright and shining as if the light were a natural part of its body.

Many heterogeneous fluids grow dark and muddy with cold, but may soon be clarified again by the application of a moderate heat. Red port wine is sometimes as foul as if brick-dust were intermixt with it, but will soon

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* See Hawksbee's Experiments, p. 168, 169. Second edit.

become bright before the fire, as if it had no sediment belonging to it.

How pure and simple soever a body may be in its nature, its transparency will be lost if the construction of its parts is altered. Water in froth, and glass in powder, have no transparency, but instead of it a superficial whiteness. Froth is composed of many minute bubbles, which reflect the light in so many various ways, that by the irregularity and confusion of these reflections the transparency of the matter is lost. The same thing happens when water is converted into snow, which consists of small concreted icicles branching out into various figures. The hoar frost also, consisting of the several particles of dew frozen into ice, have the same white appearance. I suspect that this intense whiteness may arise from a blending of all the colours of light, arising from so many irregular reflections and refractions of its rays in froth and snow. The powder of glass is made up of little angular bodies with polished surfaces, which reflect the light variously, and produce the same effect as in the bubbles of water. When water is consolidated into ice, its pellucidity is nearly preserved, because the structure of its parts

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is nearly the same as before. But if ice is irregularly formed, and abounds, as it generally does, with internal bubbles of an etherial fluid separated and detained in it, much of its transparency is lost, and a confused whiteness succeeds.

The quality of transparency is given by a wise ordination of Providence to that fluid substance of water, which is so necessary to the life of all animals, and is the most convenient vehicle of meats and medicines. By seeing through it so clearly, we are immediately informed whether any heterogeneous matters are accidentally intermixt with it, which might be contrary to the intention, or hurtful to the animal frame. We are enabled to judge of the purity of many other bodies by their transparency; and their inward constitution could never be so easily known on any other principle. For this property alone, glass is far more valuable than gold: for the value of gold is arbitrary, but the worth of glass is intrinsic; its cleanliness and transparency recommend it to our daily use for the common purposes of life; it renders visible the most curious and subtile processes in philosophy and chemistry; and in optics it assists the aged, and gives

to man an insight into the wonders of the creation, approaching toward that of superior beings. Whatever may become of all the strange relations about a second sight, by this we have a second sight which is not fabulous.

Matter is said to be *continuous*, when the parts of which it is composed touch or rest upon one another. When the parts are continuous in solid bodies, they must all move at once. A stick of wood, or rod of metal, cannot be moved at one end without moving the other at the same time. A musical string extended vibrates through its whole length when any part of it is struck. Sound may be communicated with a facility which can scarcely be imagined through solid bodies, when their parts are continuous. If the gentlest scratching be made with a pin at one end of the largest and longest piece of timber, it will be heard distinctly when the ear is applied close to the other end. But if the parts are discontinued, as by a crack in a bell, or by sawing the timber through, the vibrations are interrupted, and the sound is dissipated. Continuity in fluids does not render it necessary that all the parts should be moved at once, because they can slide

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backwards and forwards beside each other, so that the vibrations, being extended to a certain distance, become weaker till they vanish; but the vanishing distance will be greater in proportion as the fluid is more subtile and moveable. In the element of light it may be hard to say where these vibrations will stop, when they are propagated through a pure medium. Continuity is as necessary to the senses of feeling and seeing objects, as of hearing sounds: the blind man feels what is out of his reach by means of a stick, which he uses as a continuous medium betwixt himself and the object; and all vision is but a more refined sort of feeling distant objects, by means of that line of light which is extended from the object to the eye.

The particles of all vapours are discontinuous, and, being out of contact, can make no impression on one another, but must derive all their expansive force from some other medium, which extends them with violence, whence they are not found to exert any force, but with the concurrence of heat or fire, and being condensed by cold, they will easily return into a continuous mass. How far different bodies are continuous by their

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their sides, are comprehended within the square ABCD; but when they touch with their angles, they cannot be contained but in the square EHLM, which is twice ABCD. A mathematician will see how this may be carried on farther; and he will likewise observe, that the particles may be relaxed from their lateral disposition, or contracted from their angular, to all the intermediate dimensions. Cubes may be composed of pyramids, and they again may be composed of similar or dissimilar figures; and as these partake more of the lateral or the angular disposition, the dimensions of the mass may be changed almost to any degree, and the contact of the parts still preserved. As the parts of bodies can touch each other only at their surfaces; and as surfaces are so very much increased when the parts are farther decomposed, many unexpected phænomena may arise from such decompositions. When any substance is analyzed by a dissolving menstruum, the saturation may be sooner effected on this account. It may follow likewise, that when the solvent is rarefied by heat, it will hold more of the dissolved parts in suspension, and that when it is contracted in its dimensions by cold, a precipitation may follow mechani-

cally. These observations, though inclining to conjecture, are sufficient to shew, that though a mass of matter is very much altered in its dimensions, its continuity may still be uninterrupted.

There is another way of considering matter, so as to account for its extension, without supposing it to lose its continuity. The down of a thistle is composed of a central particle, which is the seed, furnished with elastic radii; while these lie, in what we may call their *fixed state*, within the calyx of the mother plant, a vast number of them is comprehended in a very small compass: but when they are relaxed or rarefied, as in their volatile state, a bushel might be filled with what lay in a few cubic inches. The force with which a medium, consisting of such parts, would resist compression, would be more or less according to the elasticity of the radii attached to the central particles; and if we suppose all the radii disjoined and independent of their centres, the condition of the medium will be very different.

Gravity not essential to Matter.

Another very considerable property of matter

matter is *gravity* or *weight*; which, though very extensive, is rather an accident to matter than essential to its nature. For certainly all matter has not weight. Bodies differing in kind do not preserve a constant relation to each other in respect of weight, when they are in different forms, and differently acted upon. It is the nature of iron to sink in water with a superior specific gravity; but the atoms of iron will be suspended in water. Sulphur will sink in oil; but if the oil be heated to a proper degree, (with which heating it is rarefied, and becomes specifically lighter,) the atoms of sulphur will ascend and be suspended in it for ever, so as to constitute a medicine of eminent service both for internal use and external application. The same is observable in other bodies: whence it is found, that relative weight is a variable thing, and that atoms in a state of separation are not affected by it, as when they are formed into masses, and compose bodies.

Were gravity essential to matter, all matter would constantly tend (or at least preserve a tendency) towards its proper centre. The matter near the earth would all tend toward the earth, and resist every other direction.

rection. The matter near the sun would all tend towards his orb. But this is by no means agreeable to nature. Here upon earth the electric fluid, a sort of matter which seems to fill the world, and is of such consequence that it seems to be the life and soul which invigorates all the rest, will move in every direction indifferently; and fire, when agitated, is rather disposed to ascend in a direction contrary to that of heavy bodies. In the regions near the sun, the matter of his light is flying off, that is, *ascending* from his orb incessantly, to replenish the world and act upon the planets. Therefore matter, considered in itself, is indifferent to every direction; which indeed is very clearly implied in what all modern philosophers have allowed, that it is indifferent to motion; because all motion must be in some direction, and we are obliged to suppose motion, before we can suppose direction. If matter, as such, has no motion of its own, it has no direction. If it is found in fact to incline to one direction rather than another, on account of what we call its weight, this happens to it from the established constitution of the world, and the operation of external causes; not from any quality inherent in the

matter

matter itself. Though fire, in its natural state, has no weight, it may be so attached by the operations of chemistry to the parts of solid matter, as to partake of their property, and increase the weight of the whole mass considerably by gravitating together with it. Some modern chemists have supposed, that matter deprived of its inflammable principle is absolutely heavier than before; which is only to express the same thing another way: for they suppose, that the inflammable principle naturally resident in it, made it absolutely lighter before the operation of calcination; we suppose that the fixity of fire makes it absolutely heavier after the operation: in either case, its *absolute gravity* is a *mutable* thing, and therefore not *essential* to the matter.

Polarity of Atoms.

A very ingenious modern chemist, who has carried the experiments of chemistry to a great height*, ascribes to the primary constituent parts, or atoms of solid bodies, a certain physical direction, which he calls *polarity*, as being analogous to that property of

* Dr. Higgins.

of the magnetic needle, which occasions it to take a polar direction. It is not meant that the atoms of bodies are turned north or south by the influence of the elements upon them; but that when the loose parts of bodies are brought together into a concrete mass, those parts, if undisturbed during their settlement, take an orderly arrangement, which is the consequence of an uniform direction in them all.

On this principle crystals are formed out of fluids; and hence it is that homogeneous masses have the same specific densities throughout their whole substance. If nature is interrupted during the specific arrangement of the parts, the concrete will not be perfectly formed, but will fail in some of its properties. So nice and critical an operation is the arrangement of the parts which form sonorous bodies, that even the barking of a dog, as I have been informed, will hurt the tone of a bell, if it happens while the cast metal is settling in the mould.

When bodies are increased by a very slow accession of parts, which is generally the case in all the stated operations of nature, the parts, as they fix themselves, have time to assume that orderly direction which is

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necessary to their permanent cohesion. Hence the stony particles which are slowly precipitated from petrifying waters, are formed into concretes which are as hard as stone itself, and, if the parts are pure enough, will compose a solid which takes a polish like the finest marble.

Many appearances are produced in bodies, to which this slow uninterrupted motion is absolutely necessary. Melted glass cools into a transparent uniform solid, when removed in its fluid state from the fire into the open air: but if left at rest to cool gradually as the fire goes out, it is formed into figured crystals; of which there is a curious account by Mr. Keir, in N° 34. Vol. LXVI. of the Philosophical Transactions. I inquired concerning this fact of Mr. Tassie, an artist who has had much experience of all the chemical preparations of glass and enamel. He assured me he had frequently observed this, when the glass and the fire were permitted to grow cold together.

Visibility the Consequence of Formation.

The *visibility* of matter seems not to be a necessary consequence of its *creation*, but only

only of its *formation*. The smallest particles or atoms of matter, in a state of solution, are invisible. A mineral water, strongly impregnated with iron, is clear and transparent as any other water; though the particles of the metal are copiously distributed through the whole body of the fluid. As soon as they begin to concrete into masses, by the addition of an astringent, they shew themselves: the water which before was clear becomes turbid, and by degrees turns nearly as black as ink. By the reverse of this operation, ink itself, with the addition of a strong acid, will be turned into a colourless water. The sky, though retaining a very large quantity of water in it, preserves its clearness so long as the moisture is in a state of solution: but as soon as the atoms of water are assembled together in masses, by means of some previous change in the temperature or density of the air, the sky is overcast, and becomes dark and cloudy. The visibility of matter therefore commences, when it concretes and assumes a form: so long as it is formless, it is also invisible. The chaos, in its primæval state, is said to have been *without form;* for which sense the Greek version uses the word αορατος *invisible:* and the scripture, referring elsewhere

elsewhere to this condition of the world, tells us, that *things which are* now *seen, were not made of things that do appear;* the meaning of which is, that visible forms were composed of invisible atoms.

Mythological Doctrines concerning Matter.

Though matter is no object of our knowledge but in its formed state, we are nevertheless obliged to understand a kind of *first matter,* out of which all the visible forms are raised, and into which they return at their dissolution. The ancient philosophers of the heathen world carried this speculation very far, supposing the first matter to be homogeneous, and accommodated to the formation of all sorts of bodies indifferently; and they had various ways of expressing it in their mythology, a science in which their religion and philosophy were represented together, in a sort of mystical expression common to both subjects, because their God was no other than Nature. Their Saturn signified this *hidden* and secret state of matter, out of which all visible forms are generated, and into which they sink again; whence this deity is reported to have devoured his own children.

children. This decay of the forms being the work of time, Saturn had also the names of Χρονος or Κρονος. He is fabled to have been married to Ops, because matter, when united to form, becomes *visible;* and Ops is called the mother of the gods, because their gods were the elements in a formed state, and were no objects of worship to them till they were visible. The Saxon idol, *Seater*, had the like meaning, and was represented with symbols expressive of his physiological character. *Proteus*, another of the heathen deities, was also a name for *first matter;* which being capable of all forms, Proteus is therefore invested with the faculty of transforming himself into all shapes, and assuming the appearance of all the elements*. The *Satyrs*, or Sylvan deities, had much the same signification with *Saturn*, to whom they were nearly allied in name: and hence they are said to have *hid* themselves in ὕλη, an equivocal word, which means either *matter* or *a wood.*

The Pythagoreans were full of this philosophy.

* ——————— ille suæ contra non immemor artis,
Omnia transformat sese in miracula rerum,
Ignemque, horribilemque feram, fluviumque liquentem.
Virg. Georg. iv. 440.

sophy, which they borrowed from the Egyptians, who seem to have been the first proprietors. They held, that the general stock of matter in the world is indifferent to every form, and that all the elements are transmutable into one another reciprocally*: that an eternal round of generation and corruption is kept up; so that nothing perishes, but only changes its appearance: that as fast as one form vanishes, another rises out of the same mass. Thus, when a carcase putrifies, animal life arises from it in another form; and on the same principle of equivocal generation, a swarm of bees may be generated from the entrails of an ox, when you have not so much as a single bee to begin with.

How far this philosophy is false, and how far

* This philosophy is delivered in the 15th Book of Ovid's Metamorphoses, the sum of which is expressed in the following lines:

> Inde retro redeunt, idemque retexitur ordo.
> ——————— rerumque novatrix
> Ex aliis alias reparat natura figuras;
> Nec perit in tanto quidquam (mihi credite) mundo.
> Nonne vides quæcunque mora fluidove calore
> Corpora tabuerint, in parva animalia verti?
> I quoque delectos mactatos obrue tauros;
> Cognita res usu, de putri viscere passim
> Florilegæ nascuntur apes.———————

far it is both true and useful, I do not here take upon me to distinguish. Some doctrines of great importance were built upon it, particularly the *metempsychosis*, or transmigration of souls, and the eternity of the world; both of them very bad, and peculiar to the philosophy of idolaters. In this article their philosophy was certainly false, that all the matter in the world is homogeneous; for there is undoubtedly an essential and radical distinction between the elements of which bodies are composed: so that neither artifice nor violence can ever transmute earth into water, or lead into gold; whence the labour of the *alchymist* is no better than a dream.

DIS-

DISCOURSE II.

On the Nature and Causes of Motion.

THE world is a great machine, subject to a variety of motions, some of which are constant, and others variable and temporary. All the elements are in motion: the matter of the earth is constantly passing into the substance of trees and plants, and as constantly returning from them again in their dissolution: the sea is moved with tides and currents; the air is agitated with winds and storms; and the light is flowing from the sun, stars, and planets, to the utmost boundaries of the universe.

If we inquire after the first and original cause of all this motion, that cause can be no other than the power of God. The whole creation bears witness to the existence and efficacy of this power; but it is not required of us to explain in what manner it exerts itself. When we say that God animates the world, as the soul animates the body, we il-

lustrate what is unknown by what is equally unknown; and we can make no just comparison betwixt any two ideas, but of such things as are known to us in a sensible manner. It is therefore sufficient to say, that as matter did not make itself, so neither can it move itself; which is the same as to say, that its motion must commence, and be continued, by the power of God. It is no more necessary that existence should imply motion, than it was necessary for nothingness to pass into existence.

But when we consider God as the cause of motion, it is not to be understood that he acts as the *immediate* cause in all the operations of nature. "Certain it is," (said the great Lord Bacon,) "that God worketh no-"thing in nature but by *second causes*: and "if we would have it otherwise believed, it "is mere imposture, as it were in favour "towards God; and nothing else but to "offer to the Author of truth the unclean "sacrifice of a lie." *

Chain of Causes.

Observation teaches us, that there is in the world

* Adv. of Learning, p. 5.

world a chain of causes, each depending on the other, and all subordinate to the power of the Creator. To follow this chain of causes, either by descending from the greater to the less, or by ascending from the less to the greater, is the proper business of philosophy; and though the several dependencies in this grand machine may in some cases be either too refined for our comprehension, or too remote for our observation; yet, so far as the system of nature is intelligible by us, it must be considered as other machines. In a watch, the first spring of motion is very remote from the index which points to the hour, but yet connected with it all the way by the successive contact of wheels and pinions, which act as so many immediate causes to one another, and all of them dependent on the elastic force of the spring. If you ask, what is elasticity? you get above the province of the watch-maker into that of the philosopher; the former of whom may answer all the ends of his profession, and be a very good watch-maker, without being able to assign the physical cause of elasticity.

In the human frame there is the same kind of dependence as in other machines. When a vein is opened in the arm, and the blood

flows out, the physician argues, that the venal blood is propelled from the extreme parts by the force of the arterial blood, which again is projected by the heart, which is kept in motion by the lungs, whose respiration depends upon the air. Yet, after all, this mechanism is of no effect without the muscular motion from a principle of life; which consideration brings us, at one more step, to the union of the soul with the body; a subject above the reach of the physician, and not necessary to his profession; insomuch that the Lecturer, who in Surgeons-hall should be bringing it in at every turn, in order to account for the construction and mechanism of the body, would be thought to have very widely mistaken the nature of his subject.

Thus also in the macrocosm, or world at large, we may be able to trace an effect through a series of causes, till we come to one at which we must stop, because philosophy will carry us no farther. When the torrent descends from the mountains, we go for the immediate cause of it to the rain, which rain is supplied by the clouds, which clouds are formed of vapours, which vapours are made buoyant by the air, and raised by the light,

light, which light is sent forth by the action at the orb of the sun; and when we have got thus far, we have reached what appears to us to be the first mover in the visible world. How this is connected with the invisible fountain of all life and power, or how it stands related to his immediate agency, it is not necessary to inquire, because it cannot possibly be known. Thus much will always be certain, that as matter has no active properties of its own, its motion must both originate and continue by the influence of invisible power; but in applying this rule to particular cases, we must admit that limitation prescribed by the poet,

> Nec Deus intersit, nisi dignus vindice nodus
> Inciderit ———

It is the proper business, and ought to be the pleasure of divines, to insist upon the influence of invisible power; but the mode of that influence being inscrutable to philosophers, they should never recur to miracle, till the mechanism of the world will carry them no farther. The grand question with them is only this, How some matter acts upon other matter, for the production of those motions which we observe in the several parts of nature?

Nature

Nature to be considered as a connected System.

It answers no purpose to consider the motion of any single body abstractedly, as a thing by itself, if there is in fact no such motion to be discovered. Speculations which carry us out of the world, can never teach us how things are conducted in the world. Nature appears to be a system of parts connected and related, and every particular part of it should be considered under this relation; without which, neither the nature nor the design of it can be understood. Take the leg of a man, and consider it without any regard to the body it belongs to: it will then have no meaning in it; neither can he that examines it, understand any thing more of it than its substance and figure, which is only to know that it has matter and form. But if you consider the same member with its relation to the body, then all these wonderful things discover themselves to us at once: first, that its vessels are supplied with the animating fluids of blood and spirits, which keep up animal life in it: secondly, that its muscles are connected with the superior parts from whence they derive their

faculty of motion: thirdly, that it is framed with due strength and exact proportion to the weight of the body, to preserve it in an erect position, and to transport it from place to place: fourthly, that it is enabled to do this effectually by its relation to the eyes, which receive light to direct all the motions of the body to their proper ends. A limb considered under these relations becomes a wonderful subject, well worthy to be admired by the anatomist and the philosopher: but if you take it out of the body, and consider it abstractedly, it is dead, motionless, and useless; except to the cannibal who could make a meal upon it.

The difference will be much the same, if any member of the frame of nature, even so much as a single atom, is taken independent of the rest. Matter subsisting as a part of the created world, has motion; but if separated from the rest, it would have no more motion than a limb divided from the body: so that he who would understand the nature of motion by taking matter abstractedly, is studying motion from that which hath no motion belonging to it. If we proceed thus, we shall not only deceive ourselves, but be great sufferers by losing sight of the true con-

construction of nature; and if we build a system upon matter so independently considered, we shall raise such a world as never did nor can exist; and, after all our pains, will be as empty as it is arbitrary.

If we would account for the motion there is in the world, it must therefore be taken as a connected system: effects must be considered as they stand related to their proper causes; and as motion is not a cause, but an effect, there can be no motion without a cause of motion. If the effect is permanent, the cause must be so too; otherwise we shall relapse into the absurdity we are avoiding, by supposing an effect of which there is no cause. It is by no means necessary that there should be but one cause of motion acting on a body at the same time. On the contrary, it is very evident there is frequently a concurrence of causes contributing to the same effect. A ship may be at once moved by the wind, the tide, and the cause that acts on projected bodies, whatever that may be. When the wind ceases, the tide may continue to act; and if that also should stop, the cause of projection will still keep up the motion till the equilibrium is restored.

Parallel between Life and Motion.

It was feigned by Descartes, the French philosopher of the last century, in order to make the world a mere independent machine, that natural bodies are indifferent to motion or rest; that if at rest, they will continue so; if in motion, they will continue to move till they are stopped by some new force. But if this doctrine is transferred to a parallel case, it will make a very strange figure. Life is an effect as truly as motion; and as no body can continue to live without the constant operation of those causes which are acting for the support of life, so no inanimate body can continue to move without the proper causes of motion. When we are told that bodies are indifferent to rest or motion, we learn no more than if it were said in other words, that they are indifferent to life or death: and if we should go on, upon this principle, to assert that a body once moved will move always unless there is something to stop it, we shall be as much mistaken as if we should affirm that the body which lives once, will therefore necessarily live on till something interposes to kill it. In account-

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ing for the nature of human life, we should be thought to assign a very mean reason, were it to be urged, that a man lives to-day only because he lived yesterday: for there are certain physical principles on which animal life is preserved, and without which it cannot possibly subsist. It is true, the principles of animal life are not very simple, nor in all respects investigable; yet reason assures us, that life must cease, and that instantly, when these are no longer present.

We must argue in the same manner about motion; that a body continues to move, only so long as the natural causes of motion continue to act upon it; and that rest, which is mechanical death, must inevitably follow when the causes of motion are no longer present to it. There may be subtile cases, in which it is as hard to trace the cause of motion, as to shew why life remains for some time in an animal body under water without respiration; but still the general assertion must be true, that every effect must have its cause, and that if the effect is permanent, the cause must be so too. If life were preserved in any human body without air in the lungs, or any remaining vital warmth at the heart to keep up the fluidity of the blood,

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this would be an absolute miracle, not to be accounted for by any principles of mechanism, nor resolvable into the doctrine of physical causes. And it would be as great a miracle if an inanimate body were to move permanently without any permanent cause; or what is worse, it would rather seem to exclude the possibility of miracles: and I cannot but wonder it was never duly considered by modern philosophers, that neither the power nor the providence of God are necessary to that body, which moves to-day only because it moved yesterday. This principle leads naturally to Atheism, and, with very little difference, is the principle on which the Greek Atheists built their system; they gave to atoms an oblique motion without any permanent cause; which, together with innate weight, essential to their constitution, carried them through the whole course of their performances in the natural world*.

True philosophy will instruct us better; that God is the source of motion, as strictly as of life; that all things *move* in him, as all intelligent

* Epicurus ait atomum, cum pondere et gravitate directa deorsus feratur, paululum declinare. Cic. de Nat. Deor. lib. i. 25.

intelligent beings *live* in him; that therefore, neither life nor motion can remain for one moment, but so long as they depend either on his own immediate power, or on such means as that power hath established in subordination to itself. Where we can observe and understand these means or intermediate causes, it is not necessary to recur at every step to the primary cause: and as it is the constant and ordinary method of Divine Power to work with natural means, reason will require us to understand them, whether we can observe them or not. The body, which we now project with ease to a great distance, would be removed no farther than the hand carries it, unless there were some power always in action, and ready to continue its motion; till, by the intervention of other natural obstacles, it is brought to a state of rest. We cannot be at a loss for a power adequate to such an effect, when we consider that the agent which occasions gravity and cohesion is always present.

Difficult Case of a Pendulous Body considered.

Let us examine this matter more particularly. We suspend a body by a line or rod, and

and call it a pendulum; and every person knows what motion it is capable of. A body thus suspended describes an arch; in one half of which it descends, and ascends in the other. We all allow that it descends to the lowest point of the arch by the power of gravity; but we cannot agree so well what happens when it gets beyond that point. Does it fall by the cause of gravity, and rise again by no cause at all? If you say it rises by the motion it has acquired in falling, I ask, what is this motion? It is nothing but an effect; and to say that it moves by motion, is to say nothing at all: for motion is not a thing by itself, as philosophers seem very falsely to have considered it; it is not a quality which a body can get possession of, and run away with; it is a mere effect, and, as such, must be referred to some cause, or given up as unintelligible. But to return to our pendulum: you will say it cannot rise by the power of gravity, because that is inconsistent with the direction of gravity. However, notwithstanding this apparent difficulty, I am persuaded that the same power which naturally carries a body downwards, will carry it any way according to the circumstances of the case: for is not the whole

arch of a pendulum described out of the line of gravity, except the first and last points of it? In falling to the lowest point of the arch, it moves for a little time very nearly in the tangent of its curve, at right angles, to the line of gravity; or, in other words, its gravity gives it motion in a horizontal direction: and if thus much, why not all the rest? Why must it leave the body at one point of the tangent line, and not continue to act upon it in the same line? If we can keep the cause and the effect together ever so little on the other side the perpendicular, the difficulty is over: then the body performs the whole course of its vibrations by one and the same cause; and the reciprocations we observe in the moving body are first in a medium, whose vibrations are continued with infinite freedom. This is more satisfactory than that other sort of reasoning, which assigns a *cause* for one half of the motion, and a *law* (which cannot execute itself) to account for the other half; and that there is a certain mathematical point at which they are miraculously changed one for the other. If the difficulty of making a body rise by gravity should shock us, let us word the matter right, and say it rises by the *cause of gravity:* or

or if this will not satisfy, let us remember that the cause of its cohesion, which is indeed but the same medium, is always present to the body in every instant of its motion, and is equally adequate to the effect: if it were not present, its parts would be separated by the resistance of the air, and the cause of gravity would carry them to the earth. Upon the whole, motion is either a *cause* or an *effect:* it cannot be a cause, for this reason, that nothing can be the cause of itself; and if it is allowed to be an effect, then all the consequences will follow, as they are above laid down.

Causes may be inferred by Rational Deduction.

Sometimes the bodily senses are able to discover the relation between the effect and its proper cause; and sometimes reason, grounding itself on past experience, will be able to do the same. When the mercurial fluid rises an inch higher to-day in the tube of a barometer than it stood yesterday, we neither see nor feel the cause of this alteration; but we come at it by very sure deduction, in the following manner: we discover,

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by experiment, that the Torricellian Vacuum is filled by the column of mercury, till the mercury becomes a counterbalance to the pressure of the external air; and that the air is the impelling cause, which drives the mercury up into the tube, and keeps it suspended there. Hence we conclude, that an alteration in the air has occasioned an alteration in the tube; and that the pressure of the atmosphere, being about one thirtieth part greater to-day than it was yesterday, drives the mercury so much higher, till it comes to an equilibrium. In the same way most of the other motions that are in the world may be referred to their proper causes, either by immediate experiment, or rational deduction. It does not follow that no material cause is concerned in any particular effect, only because we neither see nor feel its operation. There are many obvious cases in which the cause of motion may be assigned with certainty, though it is not perceived by any of the outward senses; and partly for this reason, because that which is manifest in some instances is occult in others, and distinguishable only by rational deduction. When a thermometer is held before the fire, we discover, by its rising, that the

fire enters the pores both of the glass and the inclosed fluid; which being thereby expanded, and increased in its dimensions, necessarily rises higher in the tube. Here the cause is sensibly known, because we feel the element of fire by its heat, and see it by its light. The like motion is observed in a lesser degree, when the thermometer is placed in the vacuum of an air pump, though no culinary fire is near, neither does the light of the sun act upon it; yet, though the thermometer rises only one or two degrees, a quantity too small for the human body to be sensible of*, we learn the cause of this in other more open experiments, and can thence infer with certainty, that fire is present in what we call a vacuum, to produce its natural effect of expansion; although it does not discover its presence to the senses of the body.

Different Sorts of Motion.

If we proceed next to the different kinds

* This is not accurately true under all circumstances; because the body, in a warm bath, will distinguish a difference of *one* of Fahrenheit's degrees, or even *half* a degree with practice, when the temperature of the bath is near the temperature of the blood; as I have found by experience.

of motion which are observed in the common course of nature, it will appear, that there is scarcely any such thing to be found as *uniform motion in a right line.* When a body descends from the air toward the earth, its motion is not uniform, but continually accelerated; which must be the case with every body that is acted upon by an unremitting impression. The wheel which is moved by the impulse of a stream of water, begins to stir at first with a very slow motion, and proceeds to acquire new velocity, till the impediments are a balance to the impelling force: after which it moves uniformly, but with a velocity different from what it received at the first impression, and, as near as may be, when all interruptions are allowed for, to the velocity of the stream which gives it motion. The motions observable in nature are generally in curve lines. The wind blows with a serpentine motion, as may be discerned by tracing its impressions over a plain covered with snow, or over a field of standing corn. The water of the sea is driven into waves, which rise and fall alternately; the fire of lightning descends in crooked lines or zigzags: the clouds fly in a curve parallel to the surface of the earth: the planets move

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in orbits, with a velocity not uniform in any one of them; projectiles are alternately retarded and accelerated, if their direction is above the level of the horizon. The light indeed does move in right lines, but whether its velocity is uniform at very great distances from its source, has not yet been ascertained.

Motion of the Parts of Fluids progressive and vibratory.

And here it may be seasonable to note, that fluid mediums are affected by two kinds of motion, either by an absolute progression of the parts proceeding continually forwards, as in the current of a river; or by a vibration propagated along them, without an actual progression. Of this latter sort is the motion of the sea before the wind; for it is not to be imagined, that the matter of the wave which you see a mile off, proceeds with the same succession as the figures of them are propagated from thence to the shore. The air in the form of wind moves progressively; but in the form of sound it is vibratory; it has an undulatory motion propagated through it without a progression of the parts: and

what is very extraordinary, the air may be affected by both these motions at once, with little interruption to each other. The sound of a cannon will be propagated several miles, in a direction transverse, or even opposite to that of a storm of wind: and the Florentine philosophers made some experiments, to shew that sound is propagated with the same velocity against the wind, as with it; but I have heard this contradicted by a gentleman, whose situation gives him an opportunity of making many observations on the guns so frequently fired upon the Warren at Woolwich.

In a fluid so much more subtile and elastic than air, as that of fire or light undoubtedly is, many different affections may obtain for different purposes, and all be consistent with each other. Light and heat are two of these different affections, and yet they can both take place so as to interfere with very little interruption. The rays of light will convey the images of objects through a space violently agitated with heat; though it must be observed, that in such a case the rays are affected laterally with a vibratory motion. The same fluid in electric experiments will pass freely in a current from one end to the

other

other of an iron bar, when it is heated red hot in the middle, where it might be expected to fly off, on account of the rarefaction of the medium; but there are reasons why the atmospherical pressure would confine it there, as in other parts of the bar. The undulations of water will pass through, and seem to penetrate each other in opposite directions. If a stone is cast into a still water, waves will be propagated in circles, the common centre of which is the point where the stroke was made; and if the same be repeated with another stone at a little distance, circles will be generated as before, and extend themselves through the former, without seeming to disturb the figure of them, which is an effect of so subtile a nature, that it is hard to comprehend how it can be done, though we see it with our eyes. But such is the freedom of motion in the parts of fluids, that they are capable of receiving and retaining such impressions as seem to be inconsistent. The air will bring to our ears at the same instant of time, and from various points of the compass, or, what is more strange, from the same point of the compass, the music of an organ, the roaring of cannon, the ringing of bells, and the crying of swine; and

and all of them shall be heard as distinctly at once, as if they were heard in succession. The rays of light can intersect each other with so much freedom, that if we imagine a concave sphere studied with eyes, all looking at each other, the visual rays would cross in the centre without interruption: and this is in some measure verified by the rays proceeding in all directions from the fixed stars, which are shining upon each other in every quarter of the heavens. I produce all these examples, to shew that the same means may be answering many different purposes at the same time, without confusion; and that it is therefore unphilosophical to be multiplying causes wantonly, in order to account for the different phænomena of motion, all of which may be referred to very few and simple causes.

As to the motion of the rays of light, it has been doubted of what kind it is; but I think without any reason. Some philosophers have contended for an actual progressive motion of the parts, as in the stream of a river; others, for a vibration or pulsion of the rays without progression: the former was espoused by Sir Isaac Newton, and is the more reasonable, because it is natural there should be such a circulation of matter in the

greater

greater world, as in that lesser one of the animal frame; and nobody is now in doubt whether the blood has a progressive motion through the vessels of the body. That light is not also propagated by pression, especially where it appears without proceeding from any centre of irradiation, I would not hastily affirm; because, as it hath already been observed, it is very possible that the element of fire may be capable of affections as different as those of wind and sound are in the element of air, one of which motions is progressive, the other vibratory: and perhaps this hint might lead to some probable solution of the physical difference between the rays of the sun and those from the moon, the latter of which cannot be so concentrated by any optical instrument, as to afford a sensible degree of heat.

Motion is in the Direction of its Cause.

When we consider motion as an effect arising from impulse, it will always be found that a body receives its motion in the same direction with the cause that acts upon it. If the causes of motion are various, and in different directions, the body acted upon must

must take an oblique or compound direction, resolvable into two or more simple directions: and hence it will follow, that the cause of a curvilinear motion cannot possibly be simple. Such a direction must arise from the joint effect of different causes concurring at the same instant to act upon the body; inasmuch as all simple impressions (on bodies moving freely) are rectilinear.

As all motion is in the direction of its cause, it will thence follow, that wheresoever we see a body moving in any direction, we may affirm there is a cause acting upon it in the same direction. If we see a ship in motion at a distance, we conclude that she is acted upon by the wind in the direction of her course, or according to the position of her sails. If there is no wind, then we are obliged to suppose that she is driven by a current in the same direction: for some cause there must be, and we know of none other at sea but these two; at least of no other natural causes. So, if light bodies move outwards from an electrified sphere, we conclude that they are driven by a current of electrical æther proceeding from the sphere every way in right lines. When we see the like bodies moving inwards toward the sphere,

as to their common centre, we must either conclude, as we did before, that there is another flux of matter in a contrary direction to the former, or give up one of the plainest principles in all philosophy, that motion is in the direction of its cause. Bodies moving in contrary directions must therefore infer causes in contrary directions. I know it may be said, that a ship, by her manner of tacking, may sail in contrary directions with the same wind; but this is no objection to the rule, which relates only to such bodies as *move freely*, and without any artificial interruptions. Were the ship at liberty, as a floating body in the state of nature, she would follow the course of the wind. Therefore, electrized bodies, which have nothing to do with the theory of navigation, and are at liberty to follow their natural motions, must infer the action of causes in opposite directions. When a comet, in like manner, traverses the heavens in an orbit so eccentric as to proceed in contrary directions, we must infer, as before, that it is brought toward the sun by one cause, and carried away from it by another; which two causes may possibly be those to which we have given the names of positive and negative electricity.

This principle, that all motion is in the direction of its cause, renders all *attraction* impossible in the nature of things, and resolves it necessarily into impulse; for if the earth attracts a stone by a power in the earth, then that power must exert itself in a direction contrary to that of the effect; whence all attraction, commonly so called, can be nothing but impulse. When a plaster is laid upon any part of the body, and the humours flow towards it, the plaster is said to *draw*, as if it had an attractive power of its own, which it could emit to produce the effect, but the fluids are all the while impelled *towards* it by a force from within, which we call the *vis vitæ*, propelling the fluids toward that part where there is less resistance, or greater *rarefaction*. The same plaster, with all its drawing virtue, will have no effect at all, if it is applied to a dead body.

In the motion of different bodies, it is observable, that some retain the motion they have acquired without any diminution, while others are soon reduced to a state of rest. When a body retains its motion without diminution, it is moved by such a cause or causes as would *renew its motion* if by any means it should be stopped. When a cloud is

is flying before the wind, the same wind that drives it would restore its motion, if it could be stopt by any violence: even as the sails of a windmill, after you have brought them to a state of rest, and confined them there, will receive a new motion from the wind as soon as the obstruction is removed. If you stop the motion of the lungs by an effort of the muscles, the natural causes which act upon the body tend to renew their motion, and cannot be hindered from doing it without great uneasiness.

Lasting Motions of Nature are from such Causes as would renew Motion.

Every lasting motion, therefore, is of such a nature, that it will be renewed upon its own principles: which observation is of very great importance toward accounting truly for the undecaying motions of the universe, to all of which it may undoubtedly be extended: so that if it were possible to stop the planet *Jupiter* in his orbit, or any of his satellites, the established causes that act upon them would renew their motion without any artificial impulsion: for impulsion, in the sense we commonly understand it, has no more

more share in any undecaying motion, than in the circulation of the blood in an animal, or the sap in a vegetable. Hence it is contrary to nature to suppose, that any of the lasting motions of the heavenly bodies depend upon projection in a vacuum: because if you were to stop a body moved on this principle, you have no natural means left for renewing its motion; it must either fall into the sun, and come that way to a point of rest; or be dead and motionless for ever, without some miracle to give it a new motion: but this being contrary to the conditions of every undecaying motion, which will be renewed on its own principles in the ordinary course of nature, and by means already established, is not to be admitted in philosophy. The hypothesis of a projectile impulse ought to be rejected on this farther consideration, that it obliges us to make the world a vacuum, on a supposition that those elements which are ordained to act on other matter, and to keep up the life and motion of the world, can only stand in the way to hinder the freedom of projection, and disturb the operation of an artificial and imaginary principle, obtruded upon the planetary motions against the standing laws of nature. Never-

Nevertheless, if any learned men are disposed to consider things in this way, for the exercise of mathematical reasoning, and an ingenious application of the properties of the conic sections, I have not the least objection to their speculations. Astronomy, which may proceed upon any hypothesis, and yet exhibit a true tabular calculation, will suffer nothing by it. For my own part, I do not mean to reason hypothetically, but to consider motion as a fact wherever I find it, and derive it from principles agreeable to the general order of nature. Projection must be discarded, because it is not such a principle: it is artificial and unnatural, and such as cannot be proved to obtain any-where in nature. If it is received, it must be received as an article of faith, for which we ought to have had the authority of an immediate revelation *.

 Here

* It was well observed, some years ago, by a learned philosophical gentleman of the province of New York, Cadwallader Colden, Esq. that the principle of impulsion and communicated motion, from whence we commonly deduce the flight of projected bodies, will by no means account for the motions which happen in nature, but will bring us speedily to an absurdity. "When we see a small spark (says he) gradually set a large city all in a blaze, can any man

Here let me observe by the way, that in considering the velocity of the planets, we are very apt to conceive falsely of it, by taking our ideas from the comparative velocity of smaller projected bodies, which bear no

man imagine that there is no more motion in all the parts of the city, thus on fire together, than there was in the first little spark that began the fire? that there is no more power or force in this prodigious fire, than there was in the scarce-distinguishable spark which began it? But if there be not supposed something mixed in the materials of the city thus on fire, which has a power of moving itself, all the prodigious force of motion in the city thus on fire must be supposed in the first little spark which began the fire; for nothing can give what it has not. There are innumerable other phænomena which evidently shew, that some parts of matter are self-moving agents, and which ever move, unless hindered by the force of resisting matter." See An Explanation of the first Causes of Action in Matter; printed at New-York, 1745. p. 6.

So reasoned this ingenious author; who, from the phænomena of nature, thought it necessary to attribute action to some matter, and inertness or resistance to other matter. We now express the same thing in clearer terms, and less exceptionable, by shewing which of the elements of matter are passively moved, and which are comparatively active as the established causes of motion to other matter. And to this philosophy must come sooner or later, notwithstanding all the opposition which custom and fashion may raise against those who are the first to propose this doctrine in its native form.

no proportion to their magnitude: and then it appears less credible that they should be moved by any force of the elements. When the mouse runs with all its swiftness, it is outstripped by the foot-pace of the dromedary: so the velocity of smaller bodies may be far exceeded by the gentle and equable motion of such bodies as the planets. If we will compare the planet and the cannon-bullet, let us have respect to their different magnitudes; and then, what is wonderful in the one, will be easy and natural in the other. If a bullet were taken to represent the earth, and it were placed at a distance from the centre of its orbit proportional to that of the earth, it would seem to move exceedingly slow, if it were to pass over no more than the space of its own diameter in four minutes, and revolve round its axis only once in twenty-four hours. The time of the earth's motion may be accommodated to the bullet with as much propriety as the velocity of the bullet can be accommodated to the earth. If we estimate the motions of the solar system according to their own proper scale, and not according to some diminutive comparison, the motions that obtain in it will be found suitable to the magnitude of the bo-

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dies that are placed in it; and then it will seem reasonable that their motions may be effected by very gentle forces acting insensibly upon them. The medium which produces the great effect of gravity, and occasions such accelerations, begins with a very gentle impulse, which, in the instant when it first takes place, is less than any force we can assign; and yet, by the addition of successive impulses every moment, produces very great effects.

Mediation of Corporeal Causes must be supposed in Nature.

So long as we mean to keep within the limits of philosophy, we must account for the motions of nature by referring them to corporeal causes: and where this cannot be done to satisfaction, we must either give them up, or wait with patience till some better clue of consideration, or some farther light of experience, shall come in to assist us. It is to no purpose to amuse ourselves with names and qualities which contradict the known laws of mechanism, and supersede the operations of the elements. In some cases the causes of motion may be very occult, and

yet

yet there may be no necessity for giving them up: for if all space, as later experiments teach us, is filled with active matter, (not active in its own nature, but according to the positive mechanism of the world,) there must be a general stress upon all bodies, which, if it is interrupted in any part, will occasion a motion where its action is freest, and toward that side where there is least resistance. If the internal medium within the pores of dense and solid bodies is in a more subtile and rarefied state than the external medium, all dense bodies will be attended with an atmosphere of pressure, which will carry light bodies toward them, and confine them to their surface. This principle will bear an application to all the minute instances of fluids in vessels, capillary tubes, fragments of cork floating on water, &c. In the experiments of electricity it has got possession; and as it will be found that electricity only shews us bodies affected in a greater degree, as they are at all times naturally affected in a lesser, (for the whole world is constantly electrified to a certain degree,) the same reasoning which has been adopted in that science, may be extended to all common cases. So that wheresoever we see a

body change its state from rest to motion, we may lay it down as an invariable truth, that this is the effect of matter in motion acting upon matter at rest. That two distant bodies, both supposed at rest, should be able to act upon one another so as to produce motion in each, without the assistance of any third substance, is to invest matter with a power of beginning motion in itself; which is the same as to say, that motion is essential to matter, and on this concession the materialist erects his system; so that it is not only a notion false in itself, but extremely dangerous in its consequences: and indeed I have been informed, that a French philosopher has turned to the purposes of atheism, the concession of the moderns in regard to matter and motion. We must either fall into this danger, or, when we see two bodies at rest begin to approach each other, without any visible cause, we must introduce some third body already in motion. And to justify ourselves in this practice, we have nothing to do but to shew that active matter is present, where it is neither seen nor felt: which is now abundantly done by the experiments of electricity, if it had not been sufficiently shewn before on other principles.

There

There was a time when it was the fashion, in opposition to the French system of Descartes, to banish all subtile matter out of the world, to make room for qualities in a vacuum: but later observations have reinstated a subtile medium, which is now triumphant in every branch of philosophy: and the learned in general seem more inclined than formerly to make use of it, for the explanation of the most difficult appearances in nature, not excepting even gravity itself. The inquiry is rational, and deserves to be promoted, though it may bear hard upon some popular prejudices pretty deeply rooted: for so long as *actio in distans*, be it in bodies in *particles* or in *atoms*, keeps its place in philosophy, it will be an insuperable bar to all improvements; because the most useful experiments toward the advancement of physical knowledge are those made upon the elements, all of which tend to shew us how matter interposes to produce such changes and motions as we observe in bodies distant from each other. How does the sun act upon the fruits of the earth, but by the mediation of its light? How do the clouds water the earth, but by the mediation of the air? How does the chemist produce so many changes in na-

tural bodies, but by the mediation of fire? In short, wherever distant bodies are found to affect each other, there is always something to mediate, whether we see it or not; and where this mediation is no farther to be traced, there philosophy ends, and the fictions of imagination begin; which are all of equal value, whatever name you call them by, be it sympathy, antipathy, attraction, repulsion, cohesion, elasticity, antiperistasis, or any other, ancient or modern. Nothing is intelligible but the action of matter upon matter; and though we may affect to soar above this principle in theory, we are always obliged to descend to it when we come to practice. The experiments usually made to illustrate the doctrine of *central forces*, are very ingenious and elegant, and will captivate the attention of students who are mathematically inclined; but there is this error running through them all, that the moving body is connected by a line with the centre of its motion; which cannot therefore be accommodated to motion in a vacuum, where no line of communication is supposed, but is objected to upon principle, lest it should hinder the effect. And there is this farther defect in those experiments, that the

the centrifugal force, or force in the tangent, being *consequential* to the artificial revolution of a whirling body, cannot be used as a cause of the motion; because it is the nature of all causes to be *prior* to the effect, but here it is posterior: the body is never disposed to fly off in a tangent, till it has acquired its revolution. Such a force therefore can never be applied to account for any of the celestial motions; because it comes to this absurdity, that there is nothing to account for the motion but the motion itself, or its consequence, which is the same thing.

Circulation of Matter necessary to be supposed.

If we are permitted to argue from analogy, which is the best and safest rule we can follow, it is most reasonable to suppose that all the lasting motions of the world depend upon a circulation of matter. It is evident to sense that this principle prevails in the human frame; and our view of its mechanism has been greatly enlarged by the discovery of the circulation of the blood. Where this motion begins, or where it ends, it is hard to say. The heart is the centre of it; but whether

whether the influx of the venal blood, or the efflux of the arterial, is first in order, the anatomist will find it very difficult to determine. Nothing can give without receiving; but where the giving and receiving depend on each other, as in a circle, the motion is perpetuated. Nothing is lost in the heart by what it conveys to the arteries, because it receives as much by the veins; and, so long as the machine is in order, what it receives by the veins cannot overcharge the heart, and occasion a stagnation, because it is discharged as fast by the arteries. In like manner, all the rivers run into the sea, and yet the sea is not full; and on the other hand, all the rivers come out of the sea, and yet the sea is not exhausted. What it receives it sends off in vapours from its surface, or by percolation through subterraneous passages, which, as so many vessels, communicate with the grand reservoir of waters. But this circulation is eminently carried on by a changing of the water into a new form, and a regeneration of it into its primitive form again. It goes off from the surface of the ocean in the form of a rare, invisible, expanded vapour, perfectly dissolved in the air as in a menstruum, and being for some time

suspended in that state, it is afterwards condensed into mists and clouds, then gathered into drops when it falls, which drops are all assembled into one fluid mass, and in this form it returns to the place from whence it came, to take its turn once more in the common course of evaporation, and be circulated again and again to the great promptuary of the world.

Such a Circulation is an undoubted Fact.

This change of matter into a different form, with the subsequent regeneration of it into its primitive form, is one of the great secrets of nature, whereby the world is kept from decaying, either with respect to its matter, or its motion. The source which returns upon itself can never fail; and it is of little moment to consider which is first in order, whether the vapour or the water; for the vapour will never want water to supply it, and the water will never want the return of vapour to keep its stores undiminished. How this order of things contributes to the support of the earth and its productions, is not before us now, it being sufficient here to observe, that, by means of a circulation in matter,

matter, the lasting motions of nature are maintained, and its stores unexhausted; and so general is this reciprocation, that it might be pursued through more instances than we shall have occasion to consider.

At the poles of the earth, and at the equatorial parts, the matter of the heavens must necessarily be in two very different conditions; and this never happens without a perpetual effort to restore the equilibrium by an interchanging of the matter, so as to reduce the whole to one uniform condition. To say that the matter of the heavens is rarefied in one part, and condensed in another, is only to say, in other words, that there is a reciprocal attempt in each to qualify the other, because this is the necessary consequence according to the established laws of nature; and if this continual attempt can never succeed so far as to restore the balance, the result is a perpetual motion *. The matter of the heavens being in a more fluid state at the equator, and accumulated by the daily effect of

* On this principle of restoring an equilibrium, which is interrupted before it is restored, a perpetual motion is exhibited in a barometer of a most ingenious and elegant construction, which the workman who made it was so obliging as to explain to me at Mr. Cox's Museum.

of the sun on that part of the world, will necessarily fly off sideway toward the denser matter at the poles; and the matter there condensed will, at the same time, flow in toward the equator; so that there will always be a double motion of the etherial matter in and about the direction of the meridian: and indeed the great effect of *polarity*, upon the surface of the earth, and underneath it, seems to be a natural consequence of this doctrine: it is probably the effect of two different conditions of the etherial medium, always flowing in two contrary directions. It may seem difficult to conceive how two fluid mediums, or even two conditions of the same medium, can move in opposite directions*; but nothing can be more certain than the fact. Light is a fluid medium, and air is a fluid medium; yet the rays of the rising sun will move without interruption to the west, while the wind blows strongly toward the east; and neither of these will seem in the least to hinder or disturb one another's motions;

* How two ethers, says Sir Isaac Newton, can be diffused through all space, one of which acts upon the other, and by consequence is reacted upon, without retarding, shattering, dispersing, and confounding one another's motions, is inconceivable." Opt. Quer. 28.

motions; though they must be some millions of times more intimately mixed in their progress, than the cross threads of a weaver's loom. The same thing happens at every common culinary fire, where the matter of fire is flowing outwards, so as to be capable of inflaming bodies at a considerable distance; and the matter of air as constantly rushing inwards, the effect of which is so sensible, that light bodies will be carried by it into the face of the fire. Indeed to suppose one of these motions is to suppose the other, because fire will subsist only so long as it has pure air to support it; and air cannot flow into any space already full, unless somewhat be going out of that space at the same time: so that a contrary motion in fluid mediums is not only possible and consistent, but even necessary by the common laws of nature.

And here I think we may go on to observe, that there must necessarily be different conditions in the element of air, in order to keep up a proper circulation, even as the element of water is found circulating through the world under the several forms of vapour, mist, drops, and a fluid mass, or even a solid and frozen one. Whoever shall consider the immense consumption of common air by

culinary

culinary fires, (which I have elsewhere endeavoured to calculate and demonstrate,) must needs conclude, either that this element is daily decaying, or that, according to the analogy of other cases, nature has a method of bringing it round again, through a certain course of transformation and regeneration, into its primitive condition of common air; then all will be easy and natural, and this case will agree with others of the kind. This rule may be extended even to the sun itself. How have philosophers perplexed themselves to account for the constant emission of light from the sun! A subject in which we cannot greatly err; if we suffer ourselves to be influenced by the best of all arguments, the general analogy of nature: for this will soon teach us, that whatever the particular mode may be, some there must be, of bringing his own matter back to him in circulation; without which, his source must inevitably have been exhausted some thousands of years ago. Some have argued that the matter of his light is so exceedingly rare, as to put him to little or no expence in furnishing it at the rate of above ten millions of miles in a minute, for several thousands of years together; though it is certain there

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is not a point of space in the solar system capable of holding a particle of light, but what hath such a particle in it. Nothing in nature can give without receiving; and therefore the incredibility of this plan hath inclined others to deny that the matter of light is progressive; instead of which, they have supposed that the rays of light are not emitted, but directed and determined by a vibratory motion impressed upon them by the sun, or by any other centre of irradiation, as the flame of a candle, &c. Some moderns, who deny the progression of light, are still aware that the constant flame at the orb of the sun must occasion a vast consumption of fuel; for the supplying of which, they provide a circulation of phlogiston*; supposing, that as fast as the phlogiston is consumed in some parts of the sun, it is regenerated in others, where it had been burned away and wasted some time before: and thus, with an alternate wasting and reviving of the phlogiston, the flame of the sun is perpetuated,

* *Phlogiston* is a term used by the chemists to denote the inflammable principle in any kind of fuel, whether it be oil, sulphur, animal fat, bitumen, spirit of fermented liquors, volatile vapour of smoke, resinous juice of trees, or any other that may be referred to the same class.

perpetuated, and the vibratory motion of light supported throughout the solar system. But this doctrine concerning the circulation of phlogiston is not to be introduced on such an occasion as the present, till it has been first proved to take place in such matter as we can make experiments upon; in which it hath not yet appeared that the inflammable principle, when once destroyed, is ever restored again in the common course of things. Ashes will never imbibe phlogiston, and become inflammable with long keeping; neither doth it appear that phlogiston as such ever survives the operation of the fire, because the purest alcohol, or perfectly rectified spirit, when dissipated by the action of fire, turns chiefly to an insipid water, which, if kept for a thousand years, would never turn into spirit to be again inflamed.

The circulating principle, however, in some sense or other, must be embraced, as necessary to keep up the stock of matter at the sun: but if the matter of light is progressive, this expedient of the regeneration of phlogiston (allowing it to be agreeable to nature) would be found very insufficient. Therefore it will be most easy and natural to believe, as the ancients did, that the sun,

while he supplies the world with light, is himself supplied with the same matter circulating backward to his orb in some other condition.

This principle, if admitted, will be attended with the following advantages: first, it will consist with the progressive motion of light, the source of which will be inexhaustible, because there can be no exhaustion where there is circulation. Secondly, it will agree best with that analogy which is so remarkable in the other departments of nature. The blood hath a progressive motion in the bodies of all animals; water hath a progressive motion in the earth and seas; wind hath a progressive motion in the atmosphere; and all these are kept up by the grand principle of circulation: the blood returns into its own source; the water returns to the ocean from whence it came; the air circulates with contrary currents in the atmosphere; the equatorial and polar parts are always supplying each other reciprocally, to restore an equilibrium: so that if the matter of the sun returns into itself, there will be nothing singular in the case; it will be found to do as all other matter does: and that philosophy will ever be the

best,

best, which creates the fewest principles, and explains nature in such a way as to make it consistent with itself. Thirdly, the fire of the heavens, (as the same rule of analogy obliges us to suppose,) will then be understood to burn on the same principle as other fires do upon earth, with a constant supply of elementary matter. And lastly, we shall have this farther advantage, which indeed is the greatest of all, that there will be a double motion perpetual in the system, the first and greatest of all secondary causes, accommodated in every respect to account for the revolutions of the heavenly bodies, which no other hypothesis yet invented ever hath, or ever will be able to do, with any appearance of consistency and probability.

On what Conditions there may be Motion in a Plenum.

It has been made a grand question in philosophy, whether bodies can move in a space which is filled with matter, commonly called a *plenum*? But this question cannot be answered, without first considering the condition of the matter, and stating the circumstances of the moving body. If the matter,

so filling any space, is in a fluid condition, so that the parts can slide freely over one another, they will be able to move in different or even contrary directions at the same time; and while the place of the whole mass continues the same, the place of the parts which compose it may be changed every moment. Such a sort of intestine motion arises naturally, and continues long undiminished, in a liquor, by that act of fermentation which arises from a mixture of heterogeneous principles, (such as air, fire, water, oil, salt, and earth,) in the same mass. The fulness of the space is therefore no objection to a free motion of the parts of any fluid mass amongst themselves; neither is it an objection to the motion of any solid body in such a fluid medium. If a vessel is filled with water, and closely stopped, any solid body that floats in it will move freely from one side to the other, or from the top to the bottom; because the parts of the fluid, which are displaced *before*, fall into the space *behind*, as the body leaves it. So fast as the body proceeds, just so fast do the parts of the fluid recede; so that there is neither impediment nor vacuity.

Suppose a circular groove upon any horizontal surface, and so many spherules laid in

in this groove, as just to touch one another completely, and fill up the circle. The fulness of the space is no objection to their motion: they will move for ever in the direction of the circle; because, as fast as one of the spherules is moved, so fast does the next before it make room for it, and the next behind supply the place of it. The same is true in every similar case: there may be fulness of matter, and yet there may be motion, provided there is *a circulation* amongst the parts.

If we examine into the circumstances of any solid body moving in a fluid medium, it is easy to foresee what will happen to it. When the body is moved by any artificial force or effort of violence, contrary to the nature of the medium in which it moves; the parts of the medium, in recovering their natural state, will resist the motion of the body, till the equilibrium is restored, and the body is at rest. Such, therefore, are the circumstances of all violent motion, that it is soon destroyed by resistance; though the times in which it is destroyed will differ exceedingly among themselves, according to the fluidity, tenacity, density, or subtilty of the medium in which it happens. But if the

motion of the body arises from the motion of the medium, then the resisting nature of the medium is no longer any objection to the motion of the body; neither can it be, for it is the cause of the motion; and it would be absurd to imagine, that the cause of motion can resist the motion which it causes. Hence it is plain, that no inferences from the resistances of mediums can lead us to the necessity of a vacuum. We want a vacuum only when we propose a motion which is independent of the action of every medium: but nature has no such motion, and the whole affair of resistance is therefore of little use but to practical mechanics; because the motions of nature are otherwise circumstanced.

If there is any medium more subtile than air, such as we understand by ether, that medium is the cause of gravity; and should we make experiments in order to discover whether any medium besides the air resists a falling body, what is this but to inquire, whether the cause of gravity resists the motion which it causes? Wheresoever we contradict the motions of nature, we are necessarily resisted, let the case be what it will. If we endeavour to move any body parallel to the horizon, we are resisted by the cause of

of gravity, which gives it a determination toward the centre of the earth; if it is descending in the perpendicular, and we give it a stroke downwards in the direction of its descent, we are still resisted in a proper degree; because, though we do not counteract its direction, we contradict its velocity, and therefore the cause of gravity will resist as before. The inquiry how matter resists *per se*, in an independent state, is impracticable; because no matter, subject to our inspection, is in that state.

Recapitulation.

In the preceding Discourse, these things have appeared to us, which it may be proper here to recapitulate:

1. That the heavens, the earth, the elements, and the bodies contained in them, are constantly in motion; which indeed is a fact so obvious, that it needs no particular proof.

2. That God is the *primary* cause of all this motion, but not the *immediate* cause; it being the constant method of Divine Providence to work with *intermediate* or secondary

causes, and to move some bodies by the instrumentality of others.

3. That motion is never to be considered as a thing by itself, but as an effect; which, like all other effects, must be referred to its proper causes: for the parts of the world have motion, not of themselves, but as the limbs have, by means of their connexion with the body to which they belong. Whence it follows, that any parcel of matter taken independently, can have no more motion belonging to it than a limb divided from the body.

4. That *motion* is so far analagous to *life*, that they both require the permanent action of some cause to maintain them. As life is constantly preserved in an animal body by the causes of life, so is motion as constantly preserved by the causes of motion permanently acting for this purpose: and that to suppose any thing else, is to open a door for the doctrines of Atheism.

5. That the first law of motion, invented by Descartes, is not only unreasonable, but unnecessary as an expedient; there being no occasion to understand motion as the cause of its own continuation, when there is an active

active medium adequate to all the effects of gravity and projection; which, moving with infinite freedom, can so far deceive us by the subtilty of its vibrations, as to make us believe there is no cause, where the most powerful of all secondary causes is present: and if motion be not a quality in bodies, but a mere effect upon them, this reasoning is necessary and natural, especially as we can justify the practice of assigning physical causes by rational deduction, where they are not manifest in our experiments.

6. That *uniform motion in a right line* is a phænomenon scarcely observable in nature: for that the elements and natural bodies are wont to move, either in curve lines, or with velocities not uniform. The rays of light have a rectilinear motion, but we cannot be assured their progress is uniform, it being more probable that they are retarded in a certain proportion, as they proceed to very great distances from the sun.

7. That, in accounting for motion, the same cause may be applied to different effects, because the elements are capable of such different motions as will answer many purposes at once. If this is found in the grosser fluids of water and air, much more is it true

in ether, light, or fire, which is capable of all directions, and may cross in a thousand different ways without interruption from itself: fire may heat a body, a candle may illuminate it, magnetism may give it a polar direction, electricity may repel it, and the cause of gravity give it a tendency toward the earth; and all these may be taking effect upon it at once.

8. That as all motion is *in the direction of its cause*, there can be no such thing as a power of *attraction;* because that supposes a direction in the cause which is contrary to the direction of the effect, and therefore can never happen consistently with the laws of mechanism. A cause from the earth can never bring the moon nearer to the earth; neither can a cause from the moon bring the waters of the earth nearer to that. The cause which is in the direction of a body that moves freely, is an impelling cause; and if it is impulse, it is not attraction; if it is attraction, it is not impulse; these principles being of opposite natures, and consequently inconsistent.

9. That if the same medium is found to act in different or contrary directions, it must be supposed to be in different *condi-*

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tions, or moving with some different *affection*. Air will move different ways at the same time, if it is of different densities, or moves with two different affections, as are those of wind, and the vibratory progression of sound. The etherial medium, which is finer than air, is subject to all those different affections which produce gravity, magnetism, elasticity, cohesion, electricity, heat, and illumination. How far these affections may arise from the different densities of the medium, or the different magnitude of its parts, should be considered. Sir Isaac Newton was of opinion, that even the light of the sun itself is in several conditions, as consisting of parts differing in magnitude; and thence he deduces the different refrangibilities of the coloured rays.

10. That all undecaying motion hath this property by the constitution of nature, that it will *renew itself upon its own principles*, without any foreign impulsion; which doctrine necessarily excludes the artificial force of projection from having any share in the lasting motions of the world. The bodies in the heavens are moved by such causes, as would renew their progress, if it were possible for them to be stopped; otherwise their motion

motion is not maintained upon physical principles, agreeable to what we observe in the other parts of nature; but *by miracle*, in contradiction to the common course of things. Nothing is here objected to the schemes of motion deduced from the properties of curve lines, because geometrical evidence, without physical evidence, will prove nothing in this subject. The *powers* assumed to account for motion, are indeed the proper objects of our consideration; therefore it has been remarked on the centrifugal force, or force in the tangent, that it can be of no use as a power, because it is no more than a consequence of that motion which is already established without it, and, as such, cannot be brought in to account for it with any appearance of reason.

11. That the velocities of the planetary motions being vastly exaggerated by being compared with diminutive bodies, should be estimated according to the scale of their own magnitudes; whence it may be more easily conceived how a small force of the elements (comparatively speaking) may suffice to carry those vast bodies in their orbits, and turn them upon their axes.

12. That in order to account for the last-

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ing motions of the heavenly bodies, it is most agreeable to reason and observation, to admit a general principle of *circulation* in all fluid matter; which circulation certainly prevails in such parts of nature as are more immediately subjected to our examination; and may well be extended to the sun itself, and the elementary matter in the celestial spaces.

13. That the parts of any fluid medium may move freely among themselves, though they constitute a plenum; and that solid bodies may not only move in such a medium, but preserve their motion undiminished, if their motion conspires with the motion of the medium.

14. Lastly, that the resistance which bodies meet with when they are projected or moved by any act of violence, does by no means infer the necessity of a vacuum to other bodies, which are moved on other principles, according to the common course of nature.

No person, who is at all versed in philosophical disquisitions, need be reminded, that this subject of natural motion is both subtile and difficult; hard to be explained, because it is hard to be understood: therefore a candid

did reader will not be too hasty in judging my *expressions*, when even my *conceptions*, which those expressions are intended to open, may be supposed in some instances to have fallen very far below the subject.

These, however, so far as we can reach them at present, are the properties and conditions of motion: which being previously considered, we shall proceed next to the elements; and shall endeavour to shew how they are distinguished in nature, and consequently how they ought to be divided in philosophy.

DISCOURSE III.

On the Nature and Uses of the Elements.

WE give the name of elements to those simple bodies of which others are composed, and into which they are again resolved. An element, with respect to itself, is a substance so simple that it cannot be resolved into any other: with respect to other things, the elements are those materials, into some or other of which, all compound bodies are resolvable.

The ancients generally agreed that the elements are four in number; *earth*, *water*, *air*, and *fire** : and though the chemists have often disputed this doctrine, it does not appear that they have been able to establish any in its stead that will stand the test of examination; or about which they can generally

* Στοιχεια μὲν καλȣμεν, γῆν, ὕδωρ, πυρ, αερα· αρχας δε λεγομεν, δια το ȣδεν εχειν προτερον εξ ȣ γεννατǫι. Stob. Ecl. Phys. ch. 13.

nerally agree among themselves. We cannot always judge of compounds from the principles into which they are chemically resolvable; because the operation which should only open and unfold the subject under trial, has the power of changing it, by a fresh composition, into some new thing which did not before exist. When wood has undergone the action of fire, an alcaline salt is discovered in the ashes; but nothing of this kind is found to exist in the wood, so long as it remains in its natural state: so that when we aim at a solution, we have a new composition; and hence the tests of chemistry are often very deceitful: yet we are obliged to have recourse to them on occasion of our present inquiry, and shall find them of great service when used with discretion.

Whatever substance will stand the trial, so as not to be divided into any others; or, which cannot be composed by the union of any others; that substance may properly be taken as an element.

Earth, in its simple state, is that white friable substance which remains in a bone, after all the other principles are burnt out of it; and will endure the utmost violence of fire, without being consumed or vitrified. The

The same element is the basis of all stones and common earths; though in the different sorts it has very different appearances, from some new arrangement of the parts, and from the introduction of foreign principles. When lime-stone is burnt, we might reasonably expect to obtain a simple radical earth by the operation; and indeed it is nearly such, being extremely white and pure, especially when it falls into powder as it slackens in the air: but we discover plainly by its effects, that fire is combined with it; and this element, in spite of all our care, will attach itself to such bodies as we attempt to analyze by exposing them to the action of it. When the alcaline or lixivial salt is all washed away from the ashes of burnt vegetables, we have a permanent substance left, which will retain its simplicity under all farther trials; and therefore we admit it as another specimen of the element of earth in its simple form. But the purest earth is obtained by the distillation of rain water, which leaves a powder at the bottom of the vessel, consisting of those fine terrestrial corpuscles, which are carried up and distributed in the atmosphere from the smoke of burnt vegetables.

Water in springs, rivers and seas, is a compound of many ingredients: but as none of the adventitious matter will rise with it into vapour, it may be procured in its simple form by evaporation or distillation: and if the fluid thus obtained be rarefied into vapour never so often, it is capable of no farther purification, and will always return by condensation into the same fluid as before. So that here we have another homogeneous substance, which we can neither destroy nor decompose, and may therefore take it as another element.

When all humidity is extracted from the air, and it is cleared of all other extraneous particles that float in it, there remains an elastic fluid, capable of contraction and dilatation in a very high degree, and distinct from all other fluids in the world except fire, which no art can separate from it entirely: and therefore, though custom hath always taken air for a separate element, yet can it never be exhibited in its simple form; and it would perhaps be more agreeable to nature to class it with fire as a fluid of the same elementary nature. By its elastic force on the surfaces of bodies, and by its obscurity, it differs from fire, which becomes luminous with

with agitation, and can penetrate to the internal substance of all bodies: in other respects it is closely allied to it, so that it is hard to say where air ends and æther or elementary fire begins, unless we allow that air is always ascertained by its superficial pressure. Such is the relation between these two fluids, that many writers have insensibly fallen into the practice of calling them by the same name. *Spirit* is applied indifferently by the chemists to fire and air. The etherial part of cyder and beer is called *spirit*, and comes forth from these liquors as a flatulent air. The etherial part of brandy is also called *spirit*, though we cannot extract any air from it, and its inflammability and heat shew it to be impregnated with fire. The ancients, by the word πνευμα, do not always mean gross tangible air, but that finer etherial spirit which pervades the substance of bodies, and is to be found in the upper regions of the heaven. Dr. Hales, an English philosopher, speaks of the *aerial particles of fire*, as if there was a substance common in some degree to both fluids. So intimate is the relation between them in the experiments of electricity, that it is difficult in many cases to determine how far an effect is owing to

the air, and how far it is owing to fire: but this is a subject, the farther prosecution of which belongs to another place.

Though air cannot be obtained in a state of separation from the purer element of fire, fire itself may be found in a simple form, because fire can go where air cannot follow it: thus much at least is true, that we can remove the grosser parts of the etherial fluid called air, and leave none remaining but that subtile part of the same fluid, which can pass through the pores of glass and all other solids. This may be effected either by the air pump, the Torricellian tube, or the intense heat of a furnace. When the gross air is extracted from a pneumatic receiver, the remaining medium will easily manifest itself upon any friction or agitation; and, as it was observed by Sir Isaac Newton, will affect a thermometer the same as in any other space where the air is present. In the space at the top of the tube of a good barometer, this fluid will appear when the mercury is made to vibrate; and it is said to be capable of being expanded, when heat is applied to it, so as to depress the mercury in the tube. In the heat of a furnace, the medium is so pure, notwithstanding the air hath ac-

cess to it, that if a glass phial be hermetically closed in that heat, and, when cold, hath its neck broken off within a vessel of water, the phial will be so completely filled by the water as to shew that nothing but fire is included in it; no air, but what is attenuated to such a degree of purity as to be no longer distinguishable from fire. When a vessel is closed up without any perceptible air in it, we may then say, that nothing remains in such a space, but the medium, which penetrates all things. Whether the vessel be filled with the sun's rays, or with that invisible fluid which lies hid in the pores of bodies; whether it be dark as ether, bright and shining as the light of the sun, or intensely hot as the medium in the heart of a furnace, we call it fire; that elementary matter which is distinct from earth and water, and is more attenuated and penetrating than air.

It is rather more easy to prove that compound bodies are made up of the above mentioned elements, and are resolved into them again, by proceeding *per descensum* to discover the simples in the compounds, than to find them separately in their simple form. This may be done by examining the analysis of different bodies from the three kingdoms

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of fossils, plants, and animals. The articles of the fossil or mineral kingdom are generally more simple than those of the other two, as partaking of earth in a much greater proportion. This element is found under the different forms of metals, stones, gems, and earths of a looser texture, all of which are but earth differently modified: though it must be confessed that they differ from pure virgin earth, in this respect, that with the utmost violence of fire they will for the most part be converted into glass. The substance of glass is extremely different in appearance from the white opaque earth of chalk, lime, bones and wood ashes: yet is it well known that common glass is composed of the two earthy ingredients of sand and alcaline salt, which, being fused together in the fire, settle into that pellucid body, which no art can decompose or bring back again to its constituent materials. How different in appearance is the glass of lead from the metal in its natural form, and from the powder of red lead: the substance is still the same, but differently modified by the action of fire, which gives a new arrangement to the parts. It may seem strange to call the metal of lead by the name of earth; but when this metal

is kept in fusion over the fire, the surface of it is converted into a ponderous dust, very much resembling the dust we tread upon. Quicksilver, which appears as a white shining fluid, may be converted by repeated agitation into a black obscure powder; and a spectator, who should see it only in this latter form, would never think it capable of the former, or believe that the one had any relation to the other. The rust of iron is a red earth, which has lost its metallic form and colour, only by being corroded in a moist air; and this same red powder, with the addition of any astringent, is the matter which gives blackness to ink.

There is no reason for feigning an elementary mercurial principle as the basis of metals*. It is more reasonable to understand that all metals and minerals are but different modifications of earth: and why should that be supposed in all metals, which cannot be extracted from any one of them, and is producible only from the red ponderous earth of cinnabar? Nature does not

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* This doctrine was invented to serve the system of the alchemists: for if all metals have the same metallic basis, it was rendered more probable that they might all be transmuted into one another.

present us with a multitude of principles, but with an endless variety, arising from the different combinations of a few. The three elements of *salt*, *sulphur*, and *mercury*, which the chemists added to the four others of the philosophers, are in reality nothing more than secondary substances: and though it may be very difficult to decompose them with precision, yet in general we may learn their composition very nearly by experiment and rational deduction. Salts are either acid, alcaline, or neutral; the acid is composed of earth, water and air, and so is the neutral; the alcaline is a composition of earth and fire: and some of these are again recompounded, so as to be two removes from the simple elements; which is the case of the ammoniacal salts, and many other heterogeneous bodies. And here it is to be observed, that air and fire are capable of attaching themselves to the other elements, so as to partake of their fixed and quiescent nature, and to become as it were solids themselves in the company of other solids, till by some force they are again resuscitated and enlarged so as to assume their former volatility. One third part of the weight of some bodies is derived from such an accession of air

air or fire; and hence the chemists, when they decompose such bodies, find the ingredients fail very surprisingly in weight, when compared with the concrete body from which they are taken*. When we say that salts contain air or fire, we mean, in a fixed or quiescent state. Sulphur is composed of an impure earth, an acid salt, and phlogiston, that is fire fixed and intangled in an oleaginous vehicle. Mercury seems to be the purest metallic earth, unfixed by a cement of sulphur, and owing its fluidity to an etherial or watery principle combined with the solid parts.

Some modern chemists are superseding all the experiments of their predecessors, and would introduce, as primary elements, *acid*, *alkali*, and *phlogiston:* but earth, air, and water will account for the acid; earth and fire for the alkali; and phlogiston is nothing but fixt fire in a resinous or oleaginous vehicle, sometimes more sometimes less pure, sometimes gross and solid, as in pitch, tallow, and the sulphur of metals; and in other cases

* Hence it appears, that most bodies, when once analyzed, can never be recomposed; because the fire and air, which make a considerable part of them, go off and vanish so as never to be recovered.

cases extremely light and rare, as in smoke, vapour, and the lightest fluids. Chemistry is a dangerous field for speculation; it is a science where art runs so many divisions upon nature, and the active elements do so interfere with and disguise the others, that the chemist who resolves to be a philosopher upon his own ground, is very soon bewildered, and becomes visionary in his reasonings and principles. I think it easy enough to discover the four elements in nature itself; but when I go to look for them in books of chemistry, they are so overlaid with a multiplicity of experiments, that it is not always possible to extract any thing consistent from them; and therefore we should be cautious of meddling too far with an art which hath betrayed so many into the enthusiasm of alchemy.

Upon the whole, we do not find any sufficient ground to determine, that the elements generally acknowledged will not account for all the compositions in the mineral kingdom. If we proceed from thence to the vegetable, the case will be plainer still; and if to the animal, plainest of all.

What is the sap of plants, but water, almost simple in some cases, in others more or

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less impregnated with saline or unctuous particles? Whence do plants derive their firmness and solidity, but from earth, to which they are all reducible when consumed in the fire? And then they are joined with the matter of the mineral kingdom, in the composition of glass. When they are laid to putrify, a vast quantity of air is detached from them; and we know not how to account for the acrid taste, the aromatic and caustic qualities of many vegetable juices, but from the fire combined with them; nor for the inflammability of resinous ever-greens, but from the same cause. How far the fire of that ardent spirit, which is obtained from fermented vegetable juices by distillation, resided in the substance of the vegetable matter itself, should also be considered: but certainly it cannot all be derived from the fire applied in the operation. When the matter of vegetables is volatile, as much of it is found to be, this volatility must be ascribed to air and fire attached to it, without which neither the earthy nor the watery parts can ascend and fly off.

In animals we find the same principles as in vegetables, but differently combined and qualified. The basis of their substance is an earth,

earth, most distinguishable in the bones, the ashes of which are not fusible in the fire, nor capable of running into glass; and therefore proper to make such chemical vessels as are used for the assaying of metals, and are necessarily exposed to the utmost violence of fire.

Of all the fluids in the body, water is the principal ingredient. When blood is set by to cool, it separates into a lymph or serum, very little differing from water, and almost insipid; the remainder is a coagulated mass, consisting of the red globular particles of the blood, which are composed chiefly of earth, and, when distilled to dryness, may be reduced to ashes. The inflammability of animal oil or fat, shews that fire is fixt in it; and the production of that remarkable body, the phosphorus of Kunkel, which is made of putrified animal juices, is another proof that fire is an ingredient in the animal frame. The vapour which rises from the body in perspiration, is a farther proof that fire is present in it, because water never becomes volatile but from a mixture of fire, at least when there is any perceptible heat with it, as in the present instance. The vapour which rises from the intestines of an animal newly killed,

killed, is so inflammable, that it hath been frequently observed to take fire at a candle. A very large quantity of fixed air is disengaged from the body of an animal when it putrifies; and this is the reason why bodies become specifically lighter, and float in the water after they have lain under it a few days, appearing big and swoln as if they were inflated with wind.

The four usual elements are therefore the ingredients which discover themselves when the human body is decomposed, and it doth not appear that there are any others: all the oils, salts, and saponaceous humours, may be accounted for from the properties of fire and air, combined with earth and water. The body of man, which is at the head of the material creation, and hath always been understood by theorists as a lesser world, analogous to the greater, is sufficient by itself to confirm and illustrate our doctrine of the four elements. His bones, when the oil and phlegm are extracted, are elementary earth; his blood is a red earth floating in an insipid water as its vehicle. His vital motions are maintained by the heat of an internal fire, and the breath of his life is the element of air.

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Here it may be entertaining, and not altogether useless, to look back to the philosophy of the ancients, and take a view of their doctrine concerning the elements. They did not think it necessary to have recourse to the operations of chemistry, when they found the elements already distinguished to their hands in the constitution of nature. If we consider the order of things in the frame of the world, we find the body of the earth situated first and lowest in order, over which the water is spread, as being lighter and more moveable; next above the water is the air or atmosphere; and, above that, a purer region, to which they gave the name of fire. In respect of their weight, they naturally dispose themselves into this order: earth takes its place below water; water subsides in air; and air itself, less rarefied by fire, sinks below that which is more so. If we begin the other way, fire rises in air; air rises in water; water rises from earth. However, though the elements range themselves into a natural order, we cannot absolutely say where one of them ends and the other begins, because they are blended together, and tempered so as to be subservient to each other for the good of the whole. The solid

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orb of the earth is every where moistened with water, even to the centre of the hardest rocks; and when we consider the body of the waters in the sea, we find that the element of water is not circumscribed by the surface of the ocean, but perpetually evaporating and mixing with the air, as air is always mixing itself with fire. The intermediate elements partake of those which are on each side of them: water contains earth, which is next in order below, and air, which is next above; while air contains fire, which is above, and water, which is next below it.

The ancients had many curious observations on the native temperatures of the elements, which are heat, cold, dryness, moisture, and are exactly equal in number to the elements themselves. The earth, they said, is cold and dry; water, cold and moist; fire, hot and dry; air, hot and moist: and that there is a wonderful affinity and diversity observed in the appropriation of these qualities, so as to constitute an harmony in the elements, like to that harmony which is found so agreeable in all other things, a *concordia discors*, whence arises the chief beauty of the world. Thus earth agrees with water in one of its qualities, and disagrees with it in another;

other: by its coldness it agrees with it; by its dryness it differs from it. Water agrees with air by its moisture, but differs from air by its coldness: air differs from fire by its moisture, and agrees with fire by its heat. Thus it comes to pass, that there is a certain proportion among them; so that as earth is to water, so is water to air; and as water is to air, so is air to fire. Whatever is agreeable to us, is rendered so by identity and diversity; and an attention to this rule is of capital use in all compositions, in which, if there is not, with all the variety that can be introduced, a sameness running through the whole, the artist fails of his end, and the piece is good for nothing. In every pleasing prospect there is a correspondence between the objects, and an endless variety in their colours; and a picture has its chief beauty from the contrariety of light and shade. There is a proportion between the sounds of music, which forms a consonance very delightful to the ear, but that delight cannot be maintained without the interposition of discords; and the sweetest passages of the piece are those where the consonance and dissonance are alternate, or nearly so, like the vicissitudes of day and night in the world,

or that of light and shade in a piece of painting. Thus the elements, being related by qualities which have identity and diversity when compared together, compose an harmony which we are never weary of admiring.

Some were wont to dispute about the dignity of the elements, which was the most excellent when compared with the rest. In behalf of earth, it was urged that the body of the earth is similar to the body of man; the one distinguished by solid rocks and softer matter, as the other is fortified with bones, and covered with flesh; the one furnished with veins of water and caverns of air, as the body of man with blood and spirit; the one yielding gold and gems, and every thing that is most precious from its mines and quarries; as the other comprehends all that is most wonderful and valuable in the animal creation. In favour of water, it was argued, that the sea is much more extensive than the land, if we look only upon the surface of each; but much more so, when we consider that vast body of waters laid up within the bowels of the earth; that the water is the source of all that rain and vapour by which the earth is enabled to support its productions; and farther, that it affords the means of

of communication to the most distant people of the globe, who transport themselves over the sea with much more ease and expedition than they could travel by land; and that the superiority of water over fire is evident, because it has the power of quenching it. For the air it may be said, that it is the great instrument of life to all animals in respiration; that there can be neither voice nor sound without it; and that fire itself cannot subsist, unless it is fed and fanned by the air: that the vapours of the sea would be of no use toward watering the land, unless the clouds were carried about by the winds. But the pre-eminence is at last given to fire, as the most active of all the elements, and indeed that which animates the rest, which renders the earth fruitful by its genial heat; makes the water useful by turning it into vapour; gives energy to the air by expanding and rarefying it; and, in a word, is the grand instrument in art and nature.

From the preceding dispute, we have at least this advantage, that we see plainly how excellent all the elements are in their several stations, and that all things work together for good under the direction of an all-wise and bountiful Creator, who, of his own good pleasure,

pleasure, hath accommodated his creatures with all things necessary to their several ways of life, and hath superadded all that is beautiful and most worthy of admiration. This is one of the best discoveries in natural philosophy, without which all other improvements are vain and lifeless.

The Platonists, who were enthusiastically fond of geometrical speculations, accommodated the geometrical solids to the several natures of the elements, supposing the atoms of fire to be *tetrahedrons;* those of air *octohedrons;* those of water *icosahedrons;* and those of earth *hexahedrons* or cubes, from their fixedness and stability: but this disquisition hath not so much sense in it as the foregoing; and therefore I shall not insist any farther upon it, but only to observe, that the Platonic scheme was extremely defective in having no regard to the *sphere;* which, though it is not classed with the regular bodies, is the most worthy of them all, and comprehends all the rest within itself.

I have been the more induced to shew what sense the ancient philosophers had of the elements, because the experimental pursuits of the present age seem to be bringing

us round again somewhat nearer to the old exploded Aristotelian doctrine of gravity and levity in the elements. The late discoveries in electricity have introduced us to the knowledge of an element which does not gravitate, at least not in its natural or volatile state; neither does it seem very clear that pure air, divested of all humidity and terrestrial adulterations, has any perceptible gravity. Boerhaave was much in doubt about it, and few men ever pursued experimental science with so much ardour and judgment as he did. The ancients knew that leathern bottles, blown up with air, were heavier than when lax and empty; but they imputed the apparent weight of such air either to the breath, or to some other accidental humidity, and therefore still persisted to assert its natural levity.

There is another doctrine of the ancients, which the moderns cannot controvert, and, now they have such a field of experiments before them, it is to be hoped they will improve upon it: it is likewise of great antiquity amongst the Greeks; for I find it in Ocellus Lucanus, one of their earliest authors, from whom I suppose it to have been borrowed by Cicero; namely, that two of

the elements are active, and the other two passive. Fire and air have the powers of motion; water and earth are only capable of receiving their impressions: of which doctrine we have an obvious instance in the body of man, which hath life and motion so long as air and fire maintain their proper stations, and perform their proper offices in it; and when they have left it, it is nothing but an inactive mass of earth and water, falling quickly into dissolution.

DISCOURSE IV.

Of Fire, its Properties and Effects.

On the several Kinds of Fire.

FIRE is that subtile fluid which remains when the air is withdrawn: it is present within the pores of all bodies, as well as in the free spaces of the atmosphere and the heavens; and it affects us with light, heat, and a sensible force. The eyes distinguish it by its splendour, the blood grows hot with its motion, and the muscles are sensible of its impulse.

Fire is commonly divided into three sorts, *solar*, *culinary*, and *elementary*. The solar is that fire which resides in the orb of the sun, as in its reservoir or fountain, and proceeds from it in the form of light. The culinary is that fire which is kindled upon earth by any artificial means, and burns in any sort of fuel. The elementary is that subtile fluid which resides constantly in all gross bo-

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dies, and is not necessarily distinguished by its heat as culinary fire, nor by its light as the solar or sidereal fire, but is known by other effects, even in a cold invisible state.

If it is true that natural effects are not to be ascribed to many different means or agents, where fewer will suffice, these three ought to be one and the same fluid, because they have the same properties and the same effects. The solar fire will burn in fuel, and act on solid matter with greater effect than the most violent fire of a furnace; the culinary fire will promote vegetation, and ripen fruits as the sun does; the elementary will light a candle, and fire gunpowder, as the culinary, and will afford a spectrum of the seven primordial colours, in common with the solar rays, or the light of an ordinary fire, and will also throw metals into fusion with a violent scorching heat.

They agree very nearly in their properties and effects, but differ as to the places of their residence: the one residing in the sun, the other in the earth, the other in burning fuel. They are likewise agitated with a different sort of motion; the solar matter, or light, moves in right lines; the culinary vibrates and tends naturally upwards; the ele-

mentary presses in with a shock to restore an equilibrium, and is diffused in all directions, instead of mounting upwards as the culinary, or being reflected according to the angle of its incidence as the solar. But still they are so radically the same, that what was one, becomes the other. The solar fire, which penetrates the opaque body of the earth, is there dissipated, and becomes elementary; and indeed the whole stock of elementary fire, distributed through the world, depends upon the solar. The elementary, agitated by any violent motion or attrition, and communicated to any proper combustible matter, becomes culinary; and the culinary, when cold and extinct, becomes elementary again.

I have premised these general observations, that we may avoid confusion, by knowing what it is we are inquiring after; and now it appears, that by the name of *fire* we understand that subtile matter so generally diffused, which, from the sun, is called light; when acting in any sort of fuel, is commonly known as burning fire; and in the pores of bodies, is called æther. As we proceed we shall find farther evidence, such as it would be improper to produce at large in this place, that

that the substance of these is one and the same; and therefore I shall speak of each indiscriminately, under the general name of *fire*, passing from one to the other as the subject shall naturally lead me.

Fire is a Corporeal Substance.

There having been different opinions of philosophers concerning fire; some contending, that it is incorporeal, and others, that it is nothing of itself, but only the effect of motion in the solid parts of bodies; it will be proper to shew, in the first place, that fire is material, and hath actual extension as a body: which will be plain from the following considerations:

1. That fire can drive out other matter from any given space; and certainly that which can expel other bodies, and take the place of them, must itself be body. If the ball of a thermometrical tube is filled with air, spirits, or mercury, fire applied underneath it will expel them all in their turns; which it cannot do, but in virtue of its own proper extension; and if it is extended, it is a bodily substance.

2. That fire may be seen to pass through a liquor

a liquor in bubbles, like air, and is therefore material as the air itself is. When a glass phial, three parts full of pure water, is placed upon live coals of wood, so as to acquire its heat by degrees lest the glass break; when it is beginning to boil, a fine transparent matter is seen to shoot in subtile streams through the bottom of the vessel, expanding itself as it ascends through the water; and, as the boiling increases, this matter enters with greater velocity, and with a greater expansive force; impelling the water before it by a true corporeal percussion, and with a power far superior to the pressure of the atmosphere, as we shall have occasion to shew in another place.

3. A fluid, subject to like laws with the elastic air, must be material as the air is. Fire, in common with air, is subject to be confined by an incumbent pressure, and released when that pressure is withdrawn. Fire would make water boil much sooner, if it were not resisted by the pressure of the atmosphere upon its surface; and therefore it boils with a very low degree of heat in the vacuum of an air-pump. Fire evaporates from an heated liquor more slowly when counteracted by the pressure of the air, which

which hinders it from being freely expanded. If two equal vessels of water, equally heated, are set to cool, one of them under the exhausted receiver of an air pump, and the other in the open air; the water under the receiver will be found to cool much faster than the other. Therefore fire is confined by an incumbent pressure, and evaporates freely when there is less resistance. The same is evinced by many experiments in electricity, where the electric fire is dissipated, unless it is resisted by the pressure of the air on the surface of electrised bodies; and hence its force is always greatest when the barometer is highest.

4. It is farther evident, that fire is a body, because light (which is the same in substance) is subject to this common law of projected bodies, that the angle in which it is reflected is equal to the angle of its incidence, which cannot possibly follow unless it is understood to be a body impinging upon a surface. That it is a body of extreme and inconceivable subtilty may be proved from the consideration of this particular case; that if light falls upon a surface, in a direction perpendicular to the surface, it is reflected from it again in the same perpendicular.

cular. It has been argued from this case, that light has not that impenetrability which is essential to matter, being thus returned by reflexion as it were into itself, and lost in its own substance. But it hath already been observed, that such is the nature of fluids, especially of this the most subtile of all fluids, that they can move in a direction contrary to themselves, by the sliding of the parts beside each other: and it is farther to be observed, that light so reflected upon itself becomes so much the more intense; which shews that there is a fresh accession of matter to the column by the reflexion.

5. Boerhaave brings it as an argument that fire is a true corporeal substance, because the rays of the sun, from a very powerful burning glass, directed to the extremity of a magnetic needle, gave motion to it as a stroke or blast would have done. But if we want any evidence that fire can affect bodies with a true corporeal percussion, we have nothing to do but to feel the shock of it in electricity; the power of which is so effectual upon the muscles, as to leave no possible doubt in the understanding. And here, in the experiments of electricity, we constantly find that the larger column has

the greater force, according to the law which obtains in other matter; from the smallest thread of an explosion, up to the column of fire in lightning; the dimensions of which far exceed all that art can produce. How are bodies thrown about, and even heavy stones cast to a great distance, by the stroke! I do not deny but that the air may also have some share in this effect; but I believe it is chiefly that of concentrating the fire and keeping it together.

6. There are experiments to shew that fire, as an actual substantial fluid, is transfused with different circumstances, and some very unexpected ones, from one parcel of matter to another. If hot water, in any measure, is added to the same measure of quicksilver which is cold, the water will give about twice as much heat to the quicksilver, as the quicksilver with the same heat would give to cold water*. How can this be, unless fire is an actual fluid, which has more room

* This is described more particularly in the Essay on the First Principles of Natural Philosophy, p. 139—142.—Experiments of the same kind with these which I made above twenty years ago, have been repeated and diversified, to prove the transfusion of fire, by Dr. Crawford, in a very ingenious pamphlet upon the nature of animal heat.

room to expand itself in the interstitial vacuities of the water, but is condensed and straitened when communicated to the closer passages of the mercury? On any other supposition, the fact is contrary to the laws of mechanics; which in all cases allow the greater momentum to the heavier matter. And hence it is certain, that fire is not the production of a motion in the solid parts of matter; because, in that case, the heavier particles of quicksilver must communicate more motion to the parts of water, than the parts of water, which are so much lighter, and have consequently less momentum, can communicate to the parts of quicksilver: whereas the effect of water on mercury is twice as great as the effect of mercury on water; and therefore it is not to be solved by any supposed action of their parts, but by the transfusion, and expansion, and condensation of an actual fluid within their pores; which fluid is the matter of fire.

7. The materiality of the rays of light is a necessary consequence of their decomposition. Whatever is immaterial must be pure and simple: but the light is a mixt substance, consisting of rays which differ in colour, and according to their colour are

 differently

differently refrangible. As light is the emanation of fire, and that which is light on the surface of a burning glass is fire at the focus of it; what is proved of light, in respect of its materiality, must be applicable to fire.

It might be sufficient to allege upon this argument, that nothing but that which is bodily can affect the bodily senses. Light may be seen, and fire may be felt: indeed the rays of the sun affect both senses at once; the sight by their splendour, and the feeling by their heat; and in the experiments of electricity, the shock of fire is so evident to the sense, that I think nothing farther need be urged to prove that fire is a sensible object, or, in other words, a corporeal substance. And therefore we shall proceed to examine some of its properties; the first and most remarkable of which is that power it has to penetrate all other bodies, and to act as well within as without them.

On the Penetrating Power of Fire.

The passage of the rays of light through the body of glass is so well known, that it need not be insisted upon; and it is almost as obvious, that the transparency of bodies

is

is entirely owing to the admission or retention of the light within their pores. But the same matter, when it is not visible by its radiancy, will be propagated freely through such bodies as are impervious to every other substance. If a thermometer is closely covered with a vessel of glass, any heat applied without side will raise the thermometer to the same height as if the glass were not interposed: and a coal of wood screwed up fast in a vessel of iron, will be ignited as effectually as if it were in the naked fire; which could not possibly happen unless the matter of fire has a free passage through the sides of the vessel. Why does a thermometer mark the same degree under the exhausted glass of an air-pump, as in the open air, but because the same degree of fire which is diffused through the atmosphere, is also diffused through what we call a vacuum? When we heat a ball of clay and cut it asunder, it will be as hot at the centre as at the surface. Water, when boiling over the fire, is as hot at the top, as at the bottom, which lies contiguous to the fire: and the same would probably be true, if the vessel were carried to a considerable height.

But how certain soever it may be that fire

hath

hath the power of penetrating all other bodies, it does not appear that the different degrees of fire can penetrate them with equal forces or in equal times. Heat and cold are not names of things essentially different, but only of different degrees of the same thing*, that is, of fire in motion; and therefore we call it the penetrating power of fire, whether we examine it in that state which affects us with a sense of heat, or in that other different one which affects us with a sense of cold. In the latter state it does not penetrate bodies with the same ease as in the former. If a thermometer, having the temperature of cold water, be plunged into a vessel of hot water, it will in any given time rise through more degrees than it will be found to sink through when removed from the hot and plunged again into the cold water. This is sufficient to verify the principle, and the trial is easily made.

When this subject first occurred to me, I had the opportunity of some very severe weather, at which time I immersed a vessel of water in a freezing mixture, wherein the thermometer sunk to 30 degrees below the

 cypher

* See the Essay, p. 160, &c.

cypher of Fahrenheit. I found that 23 degrees of cold were propagated to the centre of the included vessel in the space of five minutes. But when the same vessel, with water of the same temperature as before, was plunged into other water with an excess of heat equal to the excess of cold in the freezing mixture, the heat communicated in the same space of time amounted to 64 degrees: so that the two effects were to each other nearly as 5 to 14*.

And thus it ought to be in reason: for, when air is stirring briskly in the form of wind,

* Mr. Amontons, an ingenious author of the French academy, contrived a vessel of such a structure as to shew by inspection that heat and cold were not communicated in equal times, or that a fluid will acquire heat much sooner than it will part with it.

A B C D (fig. II. plate I.) is a cubic vessel of tin, divided into two equal cavities by the false bottom. I G is a tube of tin soldered into E F, and communicating with the lower region of the vessel at I, and also with the upper by means of another exterior tube soldered to C D. P Q is a tube communicating with the upper cavity at the orifice P, and also with the reservoir R. S is a vent or stop-cock, which being opened, the water that is poured into the reservoir will descend and fill the upper cavity of the vessel, as it is expressed in the figure, after which the orifice must be securely closed.

The

wind, it will affect bodies more powerfully than when it subsides into a calm; and fire, by parity of reason, ought to produce its effect sooner when it is more agitated. We shall also see, in the proper place, that it is the nature of fire, when in a rising state, to expand or rarefy bodies; by means of which it prepares for itself a more easy admission into their pores: but, on the contrary, when it is decreasing, bodies are thereby contracted in all their dimensions, their pores become narrower, and thus the cold helps as it were to shut the door against itself. This leads us to consider that other property of *heat*, by which fire is most generally known.

It is vulgarly supposed, that where there

 is

The vessel being thus prepared, its lower half was dipped into boiling water for the space of six seconds, by means of which the air in the lower cavity being rarefied, expanded itself through the tube I G, and drove the water forcibly up the tube P Q into the reservoir R. After which the vessel being placed in cold water, the water began to descend from the reservoir, but did not regain its former station in less than 18 or 20 seconds. The trial was many times repeated, and always with nearly the same event. My experiment gave the ratio of 5 to 14, this of Mr. Amontons gives that of 6 to 18: and if we consider that the two experiments were made at very different ſtages of heat and cold, the results are perhaps as near as they ought to be.

is most heat, there is most fire: but heat is rather owing to a particular motion of fire, than to the quantity of it. When the air is stirred into wind, its quantity is much the same as before, and its weight differs but little upon the barometer. Its effects as wind are owing to its motion; and these effects are most violent when the wind moves in contrary directions, as in the whirlwind, and in some particular hurricanes. So it is in the sea, when the wind is one way and the tide another; or when two streams meet and form an eddy. It is on this principle that fire affects bodies with heat. So long as the rays of the sun proceed without disturbance and preserve their parallelism, but little heat arises from them: but when they are thrown together in various directions, and returned upon themselves by the action of the air, or by attrition, or by a variety of reflexions, or by the refractions of a common burning glass throwing them into a focus, so as that they work together with an expansive force, then they never fail to affect us with a sense of heat: and if their agitation is both complicated and violent, they will tear in pieces and dissipate the bodies they act upon. Near the surface of the earth the rays of the sun

sun produce a much greater heat, on account of their various reflexions, first from the matter of the atmosphere, and then from the earth itself, but more especially if the ground is hard and dry, or of a light colour. Nothing reflects the heat of the sun more intolerably than sand; and the reason is plain, if we consider that the particles of sand are little angular bodies with many sides and polished surfaces, so as to throw the rays that fall upon them into a multitude of directions, and thereby keep up and increase the agitation. Most people have opportunities of observing how much the heat is increased when the sun's light is reflected from the ground and from the walls of buildings in a public street: and so great is the tumult which arises on this principle, that it may be perceived with the naked eye when the air is viewed obliquely near a south wall, or over a field of ripe corn, or along the fallow ground; and this vibratory motion is most perceptible in a season of drought, when it is generally understood as a prognostication that the drought will continue for some time. When this motion is not visible to the naked eye, but the horizon and the objects near it appear steady and distinct, even then a good

telescope, which magnifies about sixty times, will shew the light to be in such agitation, that the horizon of the earth will look like the horizon of the sea in a storm, and the objects placed upon it will seem as unsteady as a vessel tossed upon the waves: but whoever would see this tumult in the greatest perfection, must view it about the middle of the day, in the summer time, when the sun is most powerful. As we ascend higher in the air, we get above this disorder which prevails near the surface of the earth, and find a more quiet, and consequently a colder region: insomuch that if a mountain rises to more than a mile in perpendicular height, the rays of the summer sun have not power enough to dissolve the snows which lie upon the head of it. The vibratory motion with which light and fire are affected when they give us a sense of heat, may easily be distinguished by the sight when objects are viewed through a heated medium. If the flame of a candle is interposed between the eye and the objects viewed by it, in the day time, those objects which are seen a little above the point of the flame will seem to have an undulatory or dancing motion; because the rays of light which come across the heated medium,

medium, are disturbed and thrown out of their rectilinear course by the motion communicated to them by the flaming body. The same fluctuating motion in the visual rays is still more easily observed over a dish of burning charcoal: but it is never so conspicuous as over a lime-kiln, when the fire hath subsided, and the stones have acquired their full heat. The objects then viewed through the heated vapour appear to tremble in such a manner as to shew us, that the rays of light are disturbed in their progress, and that the motion of fire, when it gives heat, is not progressive, like that of the rays of light, but vibratory: and this gives the reason why light passes instantaneously through transparent bodies, while heat makes its way more slowly and by degrees. The most violent blast of air is not found to affect the rays of light when it blows across them: but if the matter of fire strikes upon them, when it is so agitated as to give heat, they are staggered in their course, and no longer give us a steady sight of those objects from which they are either emitted or reflected. If a refracting telescope is pointed toward a star of the first magnitude, and a candle is held near the farther end of it, so as to illuminate

the object glass strongly, the star will appear like a train of wild-fire streaming into the tube. The matter from the candle strikes upon the rays from the star, and meeting them at various angles disturbs their parallelism so that they enter the glass in many directions; after which the object is lost in the confusion of its own rays.

It hath already been noted by the way, that it is the nature of heat, when in a rising state, to expand or rarefy both solid and fluid bodies: and the reason is this, that, when fire is agitated with that motion which occasions heat, it always acts as if it wanted more room; and this in such a wonderful manner, as if every particle of space in which it exists were a radiant point or centre, from whence it spreads forcibly outwards in every direction: and consequently when fire, thus acting, is admitted into the pores of bodies, their parts must be stretched out, and their dimensions every way increased, according to the degree of fire by which they are acted upon. This expansion by fire is universal upon all bodies, but those whose solid parts are brought nearer together by the evaporation of some fluid which the heat drives out from them: and is first to be observed in the

fluid of air, whose bulk, by the heat of boiling water, is increased one third, and with the heat which iron has when it is growing white, hath its elasticity augmented somewhat more than four times, as has been found by experiment. Most of the effects of air are owing to this expanding force of fire, which gives it what we call its elasticity: and though some have reasoned as if elasticity were some property in the parts of air itself, experience shews that this seeming property in the air depends entirely on the fire intermixed with it. When air is united to any solid matter in a quiescent state, and is suddenly opened and rendered volatile again by the penetrating power of fire, it is extended to an incredible degree, and its force becomes amazingly great. This is the reason why gunpowder exerts such a wonderful force, the actual ratio of which was investigated by a learned mathematician of the Royal Society, who was happy in his address at calculations grounded upon experiments*. He found that the air which is volati-

* The person here alluded to, was Mr. Benjamin Robins, and the account is to be found at large in his works: but there is an abstract of his doctrine in vol. viii. p. 259 o the Transact. Abr.

volatilized from fired gunpowder occupies about 250 times as much space as when it lies quiescent in the gunpowder: and that the space to which this is again expanded by the heat of the flame, is about four times as much: so that the force or pressure of fired gunpowder is about 1000 times greater than the pressure of the atmosphere; which being equal to 14 pounds upon every square inch, the force of gunpowder upon the same must be equal to 14000 pounds; which will account for the astonishing effects of cannon balls.

The particular action of gunpowder is thus accounted for: the sulphur being easily inflamed, as containing in it a large quantity of fire* or phlogiston, is kindled suddenly by the powdered charcoal which is an ingredient of the composition: and the subtile fire of the sulphur, by opening the body of the nitre, sets all its fixed air at liberty, which being extended to great dimensions, and at the same time rendered violently elastic by the heat, explodes with a great noise, and when

† Εστι δε το θειον ὡς πυρ ανεψυγμενον, ουκ ετι θερμον κατ' ενεργειαν αλλα δυναμει. "Sulphur is as it were fire turned cold, not any longer hot in effect but in capacity." Nemes. chap. v.

when confined exerts a force which far exceeds all the destructive engines in use with the ancients. There is a singular circumstance which attends the firing of gunpowder; that although it seems to generate its own air, and expand by the force of its own materials, a seed of the common thistle with its down, or any other light body, suspended near some fired gunpowder, is always driven *inwards* toward the powder before it is driven *off* by the blast. The discovery of gunpowder in the latter ages of the world, about two centuries before those experiments of electricity, which have given us such a new and enlarged prospect of the doctrine of fire, is a fact not to be accounted for but from the consideration of Divine Providence, which opens a way at the proper time to such inventions as may tend either to the instruction or the correction of mankind.

There is another similar composition, in which the power of fire is as great, if not greater, than in gunpowder; it is made of sulphur and nitre as the other, but with the addition of salt of tartar. As the sulphur melts over the fire, its acid is strongly united to the alcaline salt, and the nitre is thereby bound up and confined, till it explodes with the

the greater violence, by removing the obstruction all at once. This composition cannot be applied to any such purposes as gunpowder, because it is very slow in its operation, and cannot be kindled with a spark. We have an obvious illustration from the effect of gunpowder, that air and fire, both of which are furnished in a wonderful manner by the ingredients, are the great agents in art and nature; the proofs of which are so numerous, that they will be meeting us continually as we proceed, whether the works of art, or those of nature, are the subjects of our consideration.

Water is also expanded with very great force by the action of fire; and it is rarefied to a much greater degree than even air itself. When fire is combined either with air or water, it acts by their interposition upon the surfaces of bodies, which by itself it would easily penetrate, and make its escape insensibly. Water rarefied about 800 or 1000 times, is commonly expanded in the air, and must contribute something to the effects of it; but when water boils over the fire, a vapour rises from it, so powerfully extended by the fire which raises it, that if it is confined, it will force its way through the strongest

vessels

vessels of iron. The instrument called an æolipile, or wind-ball, is contrived to shew the generation and force of steam. It has a long narrow neck with a small aperture, through which the steam rushes with great violence in the form of a factitious wind, which will blow up and brighten a coal of wood, or put out a candle, and feels as a strong blast when received upon the hand.

If the steam of boiling water is at liberty, the water never conceives more than a certain degree of heat with the act of boiling; but if the steam is confined in a close vessel, it re-acts upon the water, and raises the heat so much higher, that the water will keep lead itself in fusion; and so penetrating is the vapour, that it will soften the marrow-bone of an ox in a few minutes. An instrument was contrived on this principle, which is called Papin's Digester, from the name of its inventor, and from its penetrating, dissolving, and as it were digesting, such solid substances as are exposed to the effect of it. It is made of brass, copper, or iron; its cover is strongly screwed down, and there is a valve in the top which answers the purpose of a regulator, keeping the heat under

a proper limitation, lest the vessel burst*. The steam of boiling water is also applied as a mechanical force for the lifting of great weights, and is particularly useful in what is called a *fire-engine*, for raising water, and draining coal mines. The steam is conveyed into

* The following account of an accident with one of these instruments will give us an idea of the force of steam. "Having fixed all things right, and included about a pint "of water, with two ounces of a marrow bone, we placed "the vessel horizontally betwixt the bars of the grate about "half way into the fire, and in three minutes time I found "it raised to a great heat; and perceiving the heat in a "very short time become more raging, I stepped to the "side-table for the iron wherewith I managed the digester, "in order to take it out of the fire, when on a sudden it "burst, as if a musquet had gone off. A maid that was "gone a-milking heard it at a considerable distance, and "the servants said it shook the house. As I had foretold, "the bottom of the vessel that was in the fire gave way; "the blast of the expanded water blew all the coals out of "the fire all over the room. All the vessel together flew "in a direct line across the room, and hitting the leaf on a "table, made of inch oak plank, broke it all in pieces, and "rebounded half way of the room back again. No where "in the room could I perceive the least sign of water, "though I looked carefully for it, and, as I said before, I "had put a pint into the digester; save only that the fire "was quite extinguished, and every coal black in an in-"stant." See Phil. Trans. Abr. vol. viii. p. 465.

into a large cylinder or barrel of iron, in which a very heavy piston of the same metal is raised; when the piston is to fall, the steam is suddenly made to collapse by the injection of some cold water, which immediately condenses it, and makes a vacuum, so that the piston is forced down again by the pressure of the atmosphere. By these alternate risings and fallings of the piston, many of which are performed in the space of a minute, the machine acts on the work of a forcing pump, by which the water is raised, and discharged at the proper place. This machine, considering the vast force of it, is one of the simplest in the world; but, like the digester, may become extremely dangerous, if the fire, by any accident, should get the power over it *.

Mercury or quicksilver is also capable of being

* A workman, who with some others was employed to repair a fire-engine at Chelsea, informed me, that as they were busy about it in working it to understand the defect, the barrel, which was of great capacity, and too much worn with long use, burst on a sudden, and a cloud of steam rushing out at the fracture, struck one of the workmen who was standing by, and killed him in a moment, like a blast of lightning. His fellows ran up as soon as they could to give him assistance; but when they endeavoured to take off his cloaths, the flesh came away from the bones along with them.

being turned into an elastic vapour, with a certain degree of heat; and if experiments were made upon it, we might possibly find this vapour as strong as that of water: but instead of dwelling any longer upon vaporous expansion, it will be proper to consider the expansion of metals, all of which are extended by fire, and seemingly with an irresistible force.

If a rod of iron, six inches long, be laid in the fire till it begins to grow red, it will gain about one twentieth part of an inch in length, that is, 120th part of the whole; so that a rod of the same metal, ten feet long, would increase a whole inch in length with the same heat. That the metal is proportionably extended in breadth at the same time, may be known by passing it through an aperture which exactly fits it when cold, but will not admit it when it is heated. This is one reason why clocks go differently when carried into a hotter or a colder climate; for the times of the vibrations of pendulums are always in the subduplicate ratio of their lengths; and as the length varies with heat and cold, the times of the vibrations will be altered: and though the quantity of this alteration may be exceedingly small, if it be taken

only

only in a single vibration, yet when the vibrations are often repeated, the effect will be very sensible. An alteration of one hundred thousandth part in the time of a single vibration, will make a change of nearly one whole vibration in twenty-four hours.

In the Philosophical Transactions there is a description of a Pyrometer, intended to shew the different expansions of different metals with the same degree of heat. These experiments were made with a view to the forming of a compound pendulum, in which two metalline rods differently expanded should be so adjusted, as that the one might correct the irregularities of the other, and by so doing keep the ball of the pendulum always at the same distance from the point of suspension.

I thought the *force* of this expanding power of fire was a subject worth inquiring into, and therefore got an instrument made of a very obvious construction, for the purpose of reducing it to actual measure; by means of which instrument, the flame of a farthing candle was found to be of sufficient force to lift a weight of five hundred pounds, without any assistance from the mechanical powers, and with no great degree of heat,

as it may well be imagined, when so inconsiderable a flame was more than sufficient to supply it. In Plate II. fig. 1. A is a bar of brass or iron, placed vertically between the top of the frame *dddd*, and the shorter arm of the first lever L. This frame is made of iron; and as the chief stress is against the top, it is strengthened there with an additional bar, closely applied with cramps. The three levers with their centres are of steel, the pillars of brass: the foot or stand, to which all the parts are strongly fastened with screws and nuts underneath, is of wood. The motion of the shorter arm at L, where the bar A is applied, is to the motion (or space described, by the third lever at W, where there is a hook to hold different weights as occasion requires) in the ratio of unity to 100; so that a weight of five pounds suspended at W, will compress the bar A against the upper or horizontal piece of the frame, with a force equal to a weight of 500 pounds. Any reader who is versed in the first elements of the mechanical powers, will see that the whole instrument is a compound steelyard, proper to weigh the force under consideration. By the addition of a slender rod of deal as an index, screwed into the extremity of the

third

third lever, the space described by the weight is augmented, and made more distinguishable. Some irregularity being necessary from the construction of the machine, and a bearing of the parts upon the application of any heavy pressure, a correct measure of the value of the motion in the index was obtained by means of a screw, with a graduated plate fastened to its axis, the performance of which may be understood from the figure.

A weight of one pound being suspended at W, and the flame of a small candle applied to the bar A, the motion of the index shewed very plainly that the weight was raised by the force of the fire expanding the bar, and increasing its length in opposition to the whole force of the machine. Other weights of two, three, four, and five pounds being suspended, it still appeared that the expanding power of the fire, in so small a compass, was superior to a weight of five hundred pounds; and there is no doubt but that the flame of a farthing candle would overcome a weight of five thousand pounds with the same ease, if the parts of the instrument would conveniently bear the stress that would be necessary in such a trial.

Any person who considers with himself

how vast a weight may be suspended from a bar of iron or brass, in a vertical position, without separating the parts of the metal, that is, without overcoming the force with which they are made to cohere, may imagine how great the force of fire must necessarily be, which can so far relax the texture of iron and brass, that their parts will fall asunder with nothing but the force of gravity. All that is intended by the foregoing experiment, is to make some part of this force apparent to the sight. A farther application of the same machine to another purpose will be mentioned when we come to settle the several degrees of fire.

Thermometers are instruments which measure the degrees of heat by the expansion of bodies, which bodies are generally fluid, but solids are capable of being applied to the same use. They are of many different kinds; but all proceed on this one principle, that the degree of expansion is in all cases whatsoever* as the degree of heat; which was indeed always supposed; but the ingenious Dr.

* We ought here to say, *cæteris paribus*, because air, as we shall see presently, at the same time that it is expanded with heat, is also expanded on another principle, which is the lessening of the atmospherical column.

Dr. Brook Taylor, F. R. S. to whom the world has been so much obliged for improving the science of perspective, invented a very easy way of proving it by experiment, so that we need be under no doubt in regard to the truth of the principle *: and if fluids are equally expanded by equal degrees of heat, the converse of this must be true, that they are equally contracted by equal degrees of cold; which is indeed only to follow the same rule, *per descensum*.

* "I provided a good linseed oil thermometer, which I "marked with small divisions, not equal in length, but "equal according to the capacity of the tube in the several "parts of it, as all thermometers ought to be graduated. "I likewise provided two vessels of thin tin, of the same "shape, and equal in capacity, containing each about a gal- "lon. Then (observing in every trial that the vessels were "cold before the water was put in them, as also that the "vessel I measured the hot water with was well heated with "it,) I successively filled the vessels with one, two, three, "&c. parts of hot boiling water, and the rest cold; and at "last with all the water boiling hot; and in every case I "immersed the thermometer into the water, and observed "to what mark it rose, making each trial in both vessels "for the greater accuracy. And having first observed "where the thermometer stood in cold water, I found that "its rising from that mark, or the expansion of the oil, "was accurately proportional to the quantity of hot water "in the mixture, that is to the degree of heat." Trans. Abr. vol. vi. p. ii. p. 49.

The fluids most commonly applied to this purpose, are air, spirit of wine, linseed oil, and mercury. To make the most simple kind of thermometer, take a glass tube of some length, with a ball at the end of it, such as are commonly used for thermometers, and having heated the ball a little to expel some of the air, invert its orifice into a vessel of liquor, tinged with some colour to make its motions the more visible: as the ball grows cool, the liquor will rise up the tube, and its height will vary with the different degrees of heat and cold, by means of the expansion and contraction of the included air.

If a Florence flask is used for this purpose, with an ounce or two of some coloured spirit in it, and a tube of four or five feet long, with a small bore, is inserted into the neck, so as to have its lower orifice dipped below the surface of the liquor, (but so as not to touch the bottom,) and the juncture at the neck is made air tight by a collar of metal and some hard cement; the quantity of air being very large, and the glass so thin as to render it sensible of every sudden change, we shall have a curious thermometer, which, if placed upon a graduated scale, and ex-

posed

posed at an open window, will never be at rest; and will therefore shew us how the temperature of heat is continually changing with every breath of air, and even with the passing of a cloud. But all these aerial thermometers have this inconvenience, that as they communicate with the open air, they act also as barometers; so that the absolute degrees of heat and cold cannot be known from them, till an allowance is made for the expansions and contractions of the included air by the changes in the weight of the atmosphere, which are so great as to disturb these instruments very much in their performance as thermometers; but there may be this advantage to balance the inconvenience, that, by the rising of the spirits without an increase of heat, the weather may be predicted as by the falling of the barometer, and much more exactly, because the spirits will here rise near a foot, when the barometer sinks but an inch.

Another sort of thermometers are those which, being hermetically sealed by the melting of the glass at their orifice, after they are filled with spirits, have no communication with the outward air, and are therefore affected purely by the changes of heat and

cold. The air is expelled from the tube by the heat of a fire, the flame of a candle, &c. and when it is filled, the open end is sealed up with a blow-pipe. The instruments filled with spirits are of no use in boiling water, because pure spirit is raised to an ebullition with much less heat than is requisite to make water boil. Therefore another sort of a larger compass are made with linseed oil, which never freezes in the sharpest frost, and will not boil (in the open air) till it has nearly three times the heat of boiling water; yet these are made with difficulty, and are very sluggish in their motion: therefore the best sort of thermometer for general use is filled with mercury; which fluid, on account of its great weight, is moveable in a very fine column or thread, without adhering to the tube, as oil or spirit would do; and besides all this, it is very soon affected with heat and cold, so as to ascend and descend in the tube with great rapidity; but it is always to be observed, that the mercury applied to this purpose should be made perfectly pure and fluid by distillation *.

By

* Though I am not writing as a practical mechanic it may be proper to subjoin a few brief directions concerning the

By these instruments, all the degrees of fire within certain limits may be ascertained; and it is often of great consequence, as well as matter of amusement, to know them accurately: but there are higher degrees of fire which cannot be found by the performances of any common thermometer; therefore I shall resume this subject when I come to consider the degrees of fire, and describe an universal thermometer, which may be applied to all the possible heats of bodies, even up to iron in fusion.

Next

the method of graduating thermometers. There are two effects in nature which happen always with the same degree of heat, and the same degree of cold, or very nearly so. The first of these is the boiling of water, and the second the freezing of water into ice. The scale now in use is that of Gabriel Fahrenheit, who fixes the first point, or point of 0 degrees, at what he calls the cold of Iceland, which is many degrees below what we commonly understand as the severest weather of this climate; but in the late extreme cold of January 1776, a gentleman, who exposed a good thermometer on a bleak hill, and watched it in the night when the weather was sharpest of all, assured me that he saw it within half a degree of 0. At 32 degrees above this point, water begins to freeze; and at 212, water boils. In order, therefore, to graduate a thermometer when it is properly filled and sealed, we must place the ball of it in a vessel of snow or powdered ice, and mark the point at which it rests, which will be the

Next after the two first and most general effects of fire, which are those of penetrating all bodies, and expanding their substance to greater dimensions, we are to treat of its other more particular effects; which are, *ebullition*, *solution*, *liquefaction*, *evaporation*, *clarification*, and *induration*. Each of these we

the point of 32 degrees. Then we are to place it in boiling water, to find the point of 212 degrees. All the intermediate degrees may be found, by dividing the distance into 180 equal parts, and continuing the like division downwards to 0: which equal divisions will be true, provided the bore of your tube is equal throughout: but this very seldom happens; and therefore it will be requisite to find other points more accurately, either by following some other thermometer of known exactness as a standard, or by weighing the parts of the fluid successively as you lengthen the column of mercury in filling the tube, in order to find the irregularities of the bore at several stages. Fahrenheit himself gives two more fixed points in the scale of graduation; and he might have given a third. If water and ice and powdered sal ammoniac are mixed together, he says it brings the mercury exactly down to the *zero*, or 0; if the ball be held in the mouth of a person in health, and heated with breath, it will take the temperature of the human body, which is 96°: and it may be added, that pure alcohol, by its boiling, will give the point of 176. For some other particulars, which relate to the manner of filling the tube properly with mercury, consult Fahrenheit's own directions. Phil. Trans. Abr. vol. vi. p. 51. part ii.

we shall take according to the order in which they are here laid down.

Of Ebullition.

Fluids are raised to a boiling state, when the matter of fire passes with such force and freedom through their substance, as to be superior to the pressure of the air upon their surfaces: and when this point is gained, the fire having nothing farther to resist it, the heat never rises any higher; so that all fluids have a certain fixed degree at which they boil. The fire, which at first penetrated them slowly, and diffused itself in their pores, now goes through them at once, as it were with a flash, and transpires at the surface with such violence as to carry off the parts of the fluid in a hot vapour, which retains its heat at some distance from the fluid: and by continuing the action of the fire, the whole body of the fluid is carried off and dispersed in the air.

If it is true that the effect of boiling is owing to the fire overcoming the pressure of the air, it will thence follow, that if the pressure of the air is altered, the boiling will commence at different points of the thermometer

meter: and it is true, in all the experiments we can make, that a fluid will boil sooner, when it is less resisted by the air. When the barometer rises above the mean state of 29,5 inches, water will not boil but with an heat superior to 212 degrees; and when it falls below the mean state, the same water will boil with an heat below 212. But when the pressure of the atmosphere is almost entirely removed in the vacuum of an air-pump, the difference is very observable indeed; for water will then boil with an heat not exceeding 95 degrees, which is 117 degrees below the heat required in the open air. And hence it appears that fire and air act as antagonists in this operation of boiling; fire on the internal substance of fluids from beneath, and air upon their surface from above.

There is likewise a certain condition of the boiling fluid itself which occasions a great difference: for where the specific gravity is greater, the fire, having a denser matter to overcome, will not raise any heavy liquors to a boiling state but with a great degree of heat; of which I need produce no other examples at present than these two of alcohol (or pure spirit of wine) and mer-

cury; the former of which being one of the lightest fluids, boils at 176°; the mercury, which is the heaviest of all, at 700*. Expressed vegetable oils are not reducible to this rule on account of their tenacity, and probably for some other reasons in the natural constitution of them, too obscure to be pointed out.

That fire, when it makes a liquor boil, introduces a vacuum against the pressure of the air, is very conspicuous in the following experiment on boiling mercury. Into a common tube for a barometer pour some mercury to the depth of about 6 or 8 inches, and heat it by degrees over a dish of charcoal. When it begins to boil, you will see a cavity made by the fire lifting up the fluid from the bottom of the tube; but as soon as this happens, the air immediately presses it down again with a violent shock; and these alternate

* Fahrenheit gives us the following short table of boiling heights and specific gravities; Ibid. p. 50.

	Specific gravity.	Boiling height.
Alcohol,	8,260	176
Rain water,	10,000	212
Spirit of Nitre,	12,935	242
Lye of Ashes,	16,634	240
Oil of Vitriol,	18,775	546
Mercury,	140,000	700

alternate efforts of fire and air, which are now a balance to each other, occasion a continual knocking against the glass at the bottom. To shew that the mercury does not occasion this knocking by its weight in falling, let the tube be inclined near to an horizontal position; notwithstanding which the effect will be the same as before; and therefore it arises from the atmospherical pressure restoring the vacuum as fast as the fire produces it. By a vacuum in this place, it is obvious that nothing can be meant but a space without air; because fire in strictness can never constitute a vacuum.

Of Solution.

The solution of bodies must follow as the natural effect of fire, for these two reasons; first, because it expels that mediating substance, whatever it may be, which serves as a cement to bind their own native parts together: and secondly, because it separates their parts, by its expansive action, to such a distance that they lose in some cases their solidity, in others their continuity.

Mere earth is a friable substance, which will not ordinarily cohere, unless it is connected

flected by the addition of water, salt, oil, sulphur, or something of the like kind; all of which answer this one purpose of filling up its pores, and excluding the air or ether from a free circulation *within;* in consequence of which, it presses *without,* and acts upon the solid parts, instead of acting between them.

When fuel of any kind is burnt in the fire, it is dissolved, on this principle, that all the ingredients which bound it together are driven out of it. When a log of wood begins to burn, the water is first expelled in a moist cloud, and ouzes out at the extremities: the oily, sulphureous, and saline parts, are next carried off in a denser smoke and flame; and the residue, having lost the matter by which its pores were filled, falls asunder in the form of ashes. But fire alone, without the concurrent force of the air, will not accomplish this particular separation. A piece of charcoal closely shut up in an iron box, and laid for a long time in the strongest fire, will be unchanged: whereas, if it had been exposed for a twentieth part of the time to the action of a naked fire, where the air has free access, it would have fallen into powder.

Any kind of body, which if applied to

another body acts upon it so as to dissolve its parts, is called by the chemists a *menstruum*. The term itself is mysterious and insignificant; the application of it is very well known. Aquafortis is a menstruum to iron, and to all other metals except gold: spirit of wine is a menstruum to resinous bodies; and upon this principle all the common varnishes are made: water is a menstruum to gums and salts; and air is a menstruum to water. The two conditions requisite to the operation of a menstruum, are a certain accommodation in the parts of the solvent to those of the solvend, and a proper degree of motion or agitation for applying the parts of one to the parts of the other: of which motion fire is the general cause; and the whole affair may be thus illustrated. If a ball of clay is laid in cold water, it remains at rest, and the fluid continues pure as before: but if this water is set over the fire till it boils, the clay is soon diffused through it, and the whole continues turbid, so long as the parts of the water are agitated by the fire. But when the water grows cold, the clay subsides to the bottom, and leaves the water clear. The parts of the clay being specifically heavier than those of the water, ought to subside

side in them; but this is prevented by a motion in the parts of fire: if they are properly agitated, they are suspended in the fluid; and if they are suspended, it follows that they are agitated. From extraordinary cases we are to learn what happens in others which are ordinary. It is here evident, that fire, by its motion, separates and suspends the parts of a solid body in a fluid menstruum: where the motion of fire is violent, the solution is quickly accomplished, and a very large quantity of the solvend is sustained in the menstruum; therefore, in all ordinary cases, where the solution is slow and gradual, and the quantity suspended is but inconsiderable, the same effect is brought to pass by the imperceptible intestine motion of that ordinary degree of fire, by which the atmosphere and all things in it are constantly agitated: as the agitation increases, the cause generally betrays itself by a proportional increase of heat *. Other menstruums are rendered

* Let a piece of iron or copper be put into a glass phial with aquafortis: if it works tolerably well, place the phial under a receiver, and exhaust the air: it will then work with much more violence; so that if the air were exhausted to an high degree, it might possibly take fire and explode. While

dered such, and derive all the activity they have, by means of fire, which co-operates and gives them their proper effect. When a stone is in the condition of lime, strongly impregnated with the fire it has acquired in the operation of burning, the application of that moisture which the air carries with it will dissolve it by slow degrees, but water poured upon it will do it at once; and then the fire it contains, entering into conflict with the water, rises to a violent heat, and, as it transpires from the pores of the stone, intimately dissolves the whole substance. The utility of fire, in the works of human art and labour, is no where more conspicuous than

While it is boiling with this vehemence, contrive to drop it into a vessel of cold water within the receiver, which will very soon so check the operation, that if the glass be never so well exhausted, the aquafortis will not work with that violence so long as it is surrounded by the cold water. That the agent in this case is fire, appears very plainly; and that the motion does not *make* the heat, but that the fire and heat occasion the motion; because when the air, the natural antagonist of fire, is removed, the fire acts more freely, as it makes water boil under the same circumstances much sooner than under the pressure of the atmosphere. That the cold water, applied externally, should check the fire, is very natural; but no reason can be given why it should check the operation if it is supposed to commence upon any other principle.

than upon this occasion: for, how is it possible for men to build with any effect, either for ornament or security, unless we suppose them possessed of this wonderful secret, (for such it is, however commonly practised,) of dissolving stone, by means of fire detained and imprisoned in a cold body, and uniting it again in a more convenient manner by the mediation of water? But fire is the agent, without which nothing can be done from the beginning of this work to the end of it: for, as it changes the stone into lime at first by burning, it fixes the mortar into solidity by evaporation; of which we are to treat in due order.

Water is a menstruum to the several kinds of salts; but the power of solution is not in the water. For let some water boil over the fire in a vessel of glass, into which let sea-salt be cast by a little at a time, and we shall find that after a large quantity hath been dissolved, the water will still be transparent as before; which shews the solution to be perfect. Then let the vessel be removed from the fire, and as the water begins to cool, some salt will fall to the bottom: as it approaches nearer to the temperature of the air, more and more of the salt will be deposited:

sited: and hence we argue, that, as the fire by its greater motion keeps a larger quantity suspended, what remains at last suspended in the water is supported there by the ordinary effect of the remaining heat: so that if water could be found without fire, it would be without the power of solution. And indeed this power never fails to leave it at a certain period, when the water is frozen into ice; because a solid mass cannot act as a solvent. The same medium that gives it fluidity makes it a menstruum, and its dissolving power increases with its heat. Water with the common boiling heat will not act upon oils and sulphurs; but if wood is acted upon by water in Papin's digester above described, the smell will afterwards indicate that its oils and sulphurs are extracted; which is also clear from the friable state to which it is reduced; this being the necessary consequence when the oily parts are gone, which served as a vinculum to tie the earthy parts together. Water is therefore a solvent, so far as fire enables it to be; and therefore, in such solutions, not water, but fire is the proper agent.

When some bodies are wrought upon by some particular menstruums without the help

of

of any extraordinary fire, and other bodies are not affected by the same with all the advantages we can give them from the same element; the difference must be imputed to a mechanical fitness in one case, and an unfitness in the other, in those minute parts which constitute the different bodies: but this difference we cannot account for, because it hath its foundation in what is invisible, and must always remain so. Yet, being inclined to explain every thing, we fall upon the fruitless expedient of attractions and repulsions, which bring us into a labyrinth more mortifying, because more perplexing than our former ignorance. We may readily imagine, that the primary configurations of the parts of bodies must occasion many appearances, which would be natural and mechanical if such configurations were the objects of sense: but when we have recourse to attractions and repulsions, we introduce things which have in them nothing of a physical nature, and, when defined by different philosophers, are so full of contradiction and absurdity, that honest ignorance, which knows itself, is preferable to the knowledge of words which convey nothing to us but sound. An hungry stomach, sensible of

its own emptiness, is a symptom of health; but when it seems full, though it has nothing in it but wind, the habit is vitiated by some distemper.

Of Liquefaction.

Liquefaction is a loosening of the parts of bodies with a certain degree of heat, which are fixt with an inferior degree. This is effected by the matter of fire introduced between the parts of bodies, and driving them farther asunder by its expansive force, till they acquire a free motion amongst themselves. Experiments have now taught us, that fire is both resident and active in all bodies at all times; but, in order to liquefy them, it must act with a force which is more or less according to the subject it has to work upon. Some vegetable oils expressed from the seeds of plants continue fluid with a temperature of the air far below the point of freezing; which is wisely so ordained, that the seeds containing this oil may endure the severest frosts of the winter without being hurt in their vital principle, and so continue fit to be opened by the powers of vegetation at the proper season. Water requires a farther

ther degree of heat to keep it fluid: animal fat, bees-wax, and resinous matters, a farther still. The metals, according to their several degrees of hardness, require a different degree of fire to loosen their parts; but none of them can resist the force of it: we are accustomed to say of bodies naturally hard, that when they flow they are melted; and of bodies naturally fluid, that when they grow hard they are congealed or frozen: but the effects are similar in them all; and whatever custom may require, philosophy will justify us if we consider all water as melted ice, and a pig of lead as a mass of congealed metal. All that fluidity which is ordinary, is a lower kind of liquefaction; the difference being only this, that some substances require more, some less heat, to keep them in this state: whence it follows, that if the motion of fire were to cease, universal rigidity and stagnation would ensue: all the qualities of the ancient schools, and all attractions and repulsions of later philosophy, would be buried together in one grave, and sealed up under a monument of impenetrable brass.

As nature is now constituted, we may consider natural bodies, with the minutest of their parts, as floating in an ocean of what the

poet properly terms. *ακαματον πυρ*, *indefatigable fire*, which is moved with the same vigour now as five thousand years ago; and that the bodies sustained in it are hard or soft, fluid or solid, lax or firm, rare or dense, expanded or contracted, according to those changes in the temperature of this element, which keep up a constant systole and diastole through the whole frame of nature.

Of Evaporation.

When fire transpires from fluids which it has heated, its course is upwards, and it carries continually with it into the air that exceeding thin plate or stratum of the liquor which lies at the surface, where the fire, as it escapes, comes into contact with the air. Fluids which are light and thin yield a vapour which is spread into the air and dissipated; but others which are ponderous, as melted metals of some kinds, are separated at the surface; but instead of being carried aloft, their particles fall back upon the mass, and rest there in form of a dry dust or powder. This is the case with lead: and the powder so detached is not to be looked upon as dross or fæces, but the metal itself pulverized,

rized, and which will return to its fluidity with the application of any flaming matter of oil or sulphur.

The raising of vapour has always been a subject much inquired into by philosophers. The usual way of understanding it in the last age, was to suppose that the matter of light or fire, insinuating itself into the particles of water, turns them into vesicles, or inflated spherules, which, being specifically lighter than air, are rendered buoyant. Others have asserted that fire is no element, and that the particles of water are expanded by a repulsive power, but yet allowing that the rarefaction of the vapour is always in proportion to the heat. Of late it has been supposed, that air acts as a menstruum on water by the power of attraction; but if this is adopted, then air must be supposed to act downwards, and draw water upwards; which is not agreeable to the laws of motion, all motion being *in the direction of the moving cause.* If the rays of the sun are supposed to draw up the particles of water, this again is liable to the same objection, unless we mean it of his reflected rays, which conspire with the effect of evaporation; but the effect is of such a kind that it must be owing to a

cause

cause which diffuses itself every way, and acts in all directions; and such is the nature both of heat and the electric medium.

When a vapour rises from the surface of an heated fluid, and goes up into the air, all is consistent and rational; the fire goes off the same way, and so the cause and effect are in one direction; and therefore if we would account for evaporation consistently, we must reduce other cases to this, and argue that all slower and gentler evaporations are produced on the same principle with this, in which the operation is more quick as the cause is more violent. It is allowed by all, that heat is the general cause of vapour; and as the vapour raised by the sun's heat is in proportion to his heat, which diffuses itself in all directions near the surface of the earth and ocean, we have a cause adequate to the effect, and need not fly to any supplemental repulsions in water, or attractions in air. That vapour will not rise but in air, is very certain, because if it is ever so much rarefied, it must have air to sustain it; but the air no more raises it, than it raises the smoke which is carried upwards from a fire. The air is the vehicle, but is itself driven upwards by the fire, in common with the smoke.

Without

Without the action of the fire, the smoke can never rise, and without air to sustain it, it will fall backwards to the ground. In hot countries, much more vapour is raised than in colder climates, and the dews are excessive: but if water was dissolved by the attraction of the air, it should seem reasonable that the effect would be greater where the air is denser, because the densest air sustains the most vapour, and when it grows rarer, it lets it fall *. So great is the dampness of the air in the East Indies, that iron ordnance exposed to it grow useless with scales of rust; and instruments of steel are rusted by it even in the pocket. When the human body is most heated, most vapour passes off at the skin by perspiration. If the pores are closed, what should evaporate is reverberated, and works inwardly upon the fluids of the body, like the steam confined in Papin's Digester; and the blood rises far above its due heat into a fever, as water in that vessel rises far above the heat of boiling: and hence it comes to pass, that fevers are generally cured by making more room, and opening the pores.

It

* This is contrary to the nature of a menstruum: water sustains most salt when it is most rarefied by heat, and lets it fall when it becomes denser with cold.

It is very remarkable, that though evaporation is the consequence of heat, evaporation itself produces cold. The dew is raised by the heat of the sun, yet the dew itself is very cold. It is vulgarly conceived that the dew follows the cold; but it is found by experience, that the cold is increased by the dew, and other moist exhalations. I was informed by a gentleman who spent an hot summer in France, that it was a common practice to cool the air of a chamber by interposing a wetted window curtain for the wind to blow against. The sailors in the hot latitudes cool their liquors on ship-board by hanging their bottles to the rigging, wrapped up in a wetted linen cloth, and exposing them to the wind. The Indians themselves are acquainted with the same method, and the effect is imputed to the evaporation of the water, which is always attended with cold. Thus the sun, by raising vapour, tempers the heat of his own rays. How this comes to pass it may be difficult to say; unless the heat of the air is absorbed by vapour, as any kind of moisture is found to carry off and weaken the fire which is diffused in electric experiments, and which for this reason never succeed well in damp weather. This is assigned

signed as the reason why the body is so very sensible of cold in a moist air, because the vapour which surrounds the body draws off its natural heat. The ball of a thermometer dipped in spirit of wine, and dried repeatedly, shews the effect of evaporation on the included mercury, by making it sink many degrees. With etherial spirit and many repeated immersions and insufflations, a difference hath been found of thirteen degrees *. Such is the difference between a moist and a dry air; for a dry wind from a pair of bellows upon the naked ball of a thermometer will raise it, as we shall see hereafter. On this principle the air over a wood or forest is made colder by the evaporation from trees and shrubs. Thus plants themselves are kept in a more moderate air, and secured from the burning heat of the sun, by the vapour perspired from their own leaves; and the shade formed by vegetable bodies is found more effectual to cool us, as well as more agreeable in itself, than the shade of rocks and buildings.

It is very probable that the mists and exhalations which arise with coolness into the lower air, grow colder as they rise higher, and

* Since this was written these experiments have been carried much farther.

and contribute to that frosty coldness which frequently prevails there, even during the summer heats. I am by no means clear, that the raising of vapour from water has not a near relation to the phænomena of electricity, which are certainly found to take place among vapours when they float in the form of clouds: but however this may be, they are still under the direction of elementary fire, as they were before; many ingenious gentlemen have been seeking after the phænomena of electricity in mists and vapours, whose labours may by degrees carry us farther into this part of our subject.

Of Odours.

As a supplement to what has been said of evaporation, we may consider the phænomena of odours, which are nearly related to it. They are so generally excited, and even generated by the action of fire on various substances, that some of them seem to owe their existence to it. The powder of brimstone is inodorous when cold; but what in the world has so pungent a smell as its fiery vapour, when it is opened and diffused by burning?

ing? Vinegar, when cold, has some little odour; but when heated, it becomes exceedingly strong and penetrating. Little or no smell is to be perceived in the fresh bone of an animal; but if it is laid upon a fire, the smell will be diffused through a whole house: and it is the same with feathers, which become intolerably fœtid when scorched in the fire. This offensive smell, upon burning, is a criterion of animal substances, as distinguished from vegetable, by betraying a latent animal oil; and the experiment has been judiciously applied, to determine to which of the three kingdoms the corals and coralline bodies belong, that are taken out of the sea. All the odours that arise from putrifying bodies depend very much on the action of heat; and thence it appears to be the design of Providence, that when carcases are most subject to putrify, and become noxious with the heats of the summer, there is then a generation of flies of all kinds swarming in the air, ready to remove all offences as fast as possible by a voracious breed of maggots. In extreme cold there is no smell from dead bodies, because there is no putrefaction. As the most fragrant liquors when frozen emit

no

no smell *, so the carcases of men and beasts which have died upon the Andes, that vast ridge of mountains in South America, are reported to have been found untainted for many years.

Upon the whole, though it is common with us to impute all odours to particles of the solid subject spread abroad in the air; it is by no means improbable, that fire itself, with some particular modification of it in passing through, and circulating within certain bodies, may affect us with the sensation of an odour; like the rays of the sun, which in passing through painted glass will give to the eye the impression of particular colours, and continue so to do as long as the glass endures, without being supposed to take any thing away from the coloured body through which it passes.

Of

* Exemplar hujus rei exhibuit mihi *spiritus vitrioli volatilis sulphureus rectificatus*, solo aere in longum latumque dissipandus. Hic enim cum intensiore frigore in glaciem congelatus, etiam vitrum diffregisset, ita ut hujus fragmenta ab ipso dilapsa, ipsum ita nudum destituerent; nihilominus de ipso non solum nihil in auras divaporavit, sed ille quoque ita in glacie constitutus, ne *odorem* quidem de sese sparsit eximium; quod *intensissime* fecit simul atque tepido *calore* iterum diffueret. *Stahl*, specimen *Beccher*, p. 70.

Of Clarification.

Clarification is effected by separating the grosser particles and heterogeneous matters from liquors, so as to leave them clear and transparent; or by redissolving the parts which are tending to a precipitation, that they may be equably diffused, so as to become invisible. When precipitation is occasioned by that contraction which proceeds from cold, then heat is the natural remedy. If wine is grown thick and turbid with cold, a gentle warmth will promote a solution, which makes it clear again. Urine, when exceedingly turbid, may be restored to its former transparency by applying an heat equal to that of the human body. Some substances are purified, when the fire carries off the baser part, and leaves the finer; thus gold and silver are purified in the furnace. Other matters are purified by the fire carrying off the finer parts, and leaving those which are too gross to ascend. Thus sea-water is purified and made fresh by distillation, because the saline and bituminous parts, which make it nauseous and purgative, are not volatile enough to rise with the elementary water

which contains them. But the effect of fire is never more manifest in this work of clarifying, than when it raises a scum to the top of a boiling liquor. Many substances are rendered impure by a flatulent spirit, which being rarefied, goes off in the form of bubbles, and carries with it many of the fouler parts to the surface. On this principle honey is clarified; and when its flatulency is thus corrected, is much fitter to be used as a medicine. When impurity is occasioned by a mixture of aqueous parts, as it happens to oils and other compound bodies, a fire of 212 degrees rarefies the water into vapour, and it passes off with a crackling explosive noise. Chemists, painters, dyers, and other manufacturers, are acquainted with many processes in the course of their business, which would serve to illustrate this part of our subject. The word *purity* is best accounted for by deriving it from πυρ, *ignis*, because fire is the grand agent which purifies all things.

Of Induration.

Earthy substances, which have moisture within them, grow hard by being dried, and very hard by the application of a strong fire,

as it happens to bricks and tiles in burning. The fire effects this by driving the moisture from the clay, so that the parts which were flexible by the interposition of water, become hard and fixt. Bodies which are loose and incoherent, as dry sand, may be bound together with water, filling up those vacuities in which the air interposed to keep the parts asunder; for, so long as the air intervenes, the parts cannot be united: but the air can never be so perfectly expelled as by means of water. It is a curious secret, and of great importance in some works of art, that the steam of boiling water drives out air, and leaves a more perfect vacuum than we can make on any other principle. This was Fahrenheit's method of expelling the air from his glass tubes, in order to prepare a perfect vacuum for the reception of his mercury. He boiled a few drops of water in the ball, till the vapour rushed out as from the aperture of an æolipile, and at the proper time removing it from the fire till the vapour was nearly spent, he sealed the end of the tube at a lamp; then having inverted the end into a vessel of mercury, and carefully broken it off under the surface, so as to admit none

 of

of the external air, the tube was at once filled with the mercury.

This experiment shews that a complete vacuum is formed by the steam of boiling water; and it will help us to explain the induration of such bodies as grow hard with the fire: for when the moisture which they contain is raised to a boiling heat, its steam expels all the included air, and leaves a vacuum within the pores, so that there is now no water for the solid parts to slide upon; and the external medium pressing forcibly on the vacuum, brings the solid parts nearer, and fixes them firmly together. So long as air and moisture are excluded, the body retains its hardness, but becomes soft and flexible again when they are readmitted; nay, if water insinuates itself into their pores, and is therein frozen into ice, they are split in pieces. Even sand itself, by being first wetted and afterwards heated, so as to expel the water, may be bound into hardness; but the constituent parts are generally too large to admit of their being fixed to any degree of firmness. Hence we learn, that lime should always be tempered as it is wanted, and used while it is fresh; for then its own internal heat

heat expels the water so effectually, that the parts settle closely together, and constitute a body as firm as the stone itself; but practical workmen follow their old ways, and can very rarely be brought to pay a proper regard to philosophical improvements. The Romans made use of bricks dried in the sun, which were liable to be dissolved with wet; and hence came the proverb *laterem lavare*, "to wash a brick;" because the more such bricks were washed, the fouler they became. A strong heat is requisite to make bodies so firm as to stand the effects of the weather. Glass, which is impenetrable to all kinds of moisture, owes all its firmness to the fire.

Of the different Methods of Exciting and Collecting Fire.

The parallel rays of the sun might go on for ever and give little or no sense of heat; but as soon as they are turned upon each other by the refractions of a dioptric burning-glass, or the reflexions of a concave speculum, heat is the immediate consequence: and as every impression upon the matter of fire, except that of a plane speculum, disturbs its parallelism, it may be generally

asserted, that motion produces heat, fire being every where present to be affected by it. Even the motion of the air itself will increase the heat of the fire that is mixed with it. If a pneumatic receiver, of the most capacious kind, is well exhausted while a good thermometer is inclosed within it, the thermometer will be found to rise two degrees with the readmission of the cold air rushing in with violence through a small aperture. A cold blast of air directed by a pair of bellows against the ball of a mercurial thermometer, will raise it considerably. When this experiment has been tried in cold weather, and every necessary precaution observed, I have seen it raise a thermometer nearly nine degrees; but it is not found to produce so great an effect in the warm weather of the summer, though the effect is even then always distinguishable.

This fact is very surprising, and contrary to all expectation, that the same blast which affects the hand with cold, should be exciting a greater degree of heat. But to account for this, it must be remembered that every such blast is below the temperature of the blood, and although it raises heat, that heat will not be perceived. The reason why a wind

wind always seems colder than a stagnant air, though both are of the same degree, is this: that the body being surrounded with a warm atmosphere of its own, by means of the steam which is continually rising from it, and which will affect a thermometer at some distance from its surface, the wind removes this atmosphere, and applies itself close to the skin; and therefore must give us a greater sense of cold than a quiescent air which has no force to disturb our own natural atmosphere, which serves as a kind of clothing to the body.

The common way of collecting fire by a flint and steel, is universally known, and but little understood. The vacuities of all solid bodies are replete with fire, so that it is impossible to agitate or separate their parts swiftly without giving the same rapid motion to the element contained within them, and the effects of this motion are very extraordinary. When a piece of hardened steel is struck with a flint, some particles of the metal are scraped away from the mass; and so violent is the fire which follows the stroke, that it melts the steel, and turns it into a metallic glass. If the fragments of steel are catched upon a white paper, and viewed with

a microscope, they appear to be perfect spherules, and very highly polished. Their sphericity demonstrates that they have been in a fluid state, and the polish upon their surfaces shews them to be vitrified.

It is not every sort of agitation that raises heat in bodies. A bell, or other sonorous body, may receive a stroke, by which all the particles of the metal are thrown into a vibratory motion, which continues for some time, but is not attended with any heat. The following conditions seem to be requisite: first, that one body should be in contact with another; and, secondly, that it should move at the same time swiftly over it; which conditions are implied in the word *attrition*. The closer the contact, and the swifter the motion, so much the more sudden and vigorous is the fire. If two pieces of plate-glass are rubbed swiftly one over the other in the dark, sparks of fire will appear between them; and though the touching surfaces are so smooth and polished as to seem incapable of offending each other, yet as oft as the fire appears, some particles are scratched and torn away from the surfaces: whence it should seem, that the fire which appears is not generated between the surfaces,

faces, but drawn out of the substance*; as when the flint cuts away suddenly some parts from the steel, which it never fails to do when the fire appears. Two common pebbles, if white and transparent, will flash with fire when rubbed together properly in the dark, and smell as if they were scorched.

If the irons at the axis of a coach-wheel are applied to each other without the interposition of some unctuous matter to keep them from immediate contact, they will become

* The ancient physiologists had a notion, (in which they have been followed by many learned men, and particularly by the late Mr. Hutchinson,) that the fire which appears upon these occasions is generated out of air, and that it is rather to be ascribed to an attrition or grinding of the air between the surfaces of two hard bodies, than to the more subtile medium of fire already subsisting under that form within the bodies themselves. Many passages might be extracted from the ancients to this purpose: but the doctrine is not true. When the air-pump came into use, Mr. Boyle inquired very particularly into this matter, and found that the same, or even a greater heat, would arise when two solid bodies were rubbed together in vacuo; and thence he concluded, that the air was not necessary to that heat which arises from attrition. Mr. Hauksbee, whose experiments were made with a better and improved apparatus, discovered, that when amber was rubbed against woollen very swiftly in vacuo, the motion was attended with so great an heat, that

come so hot, when the carriage runs swiftly along, as to set the wood on fire; and the fore wheels being of lesser diameter, and consequently making more revolutions, will always be most in danger. The like will happen to the work of a mill, or any other machinery, if the necessary precautions are not taken. It is no uncommon practice with the blacksmiths, to use a plate of iron as

the amber appeared manifestly to be burned and cracked, and the woollen not only discoloured but perfectly scorched. See Hauksbee's Experiments, edit. ii. p. 26. Boerhaave was of opinion, that if air is very highly condensed, fire may arise, and be preserved by a bare attrition of it. "Let "no one imagine subterraneous fire a fiction, as if it could "not there exist without air or fuel; for this fire may arise "and be preserved by the bare attrition of condensed air, "without any other assistance: for, what heat will not air "produce, when rendered 600 times more dense than com- "mon air, as it may be at the bottom of the deepest mines? "and creditable persons have affirmed, that air, compressed "in an iron tube, has grown hot in such places. Doubtless, "in the deepest parts of the earth, bodies are pressed with "a prodigious incumbent weight, so as that a small attri- "tion may produce a great degree of heat, &c." Shaw's Chemistry, second edit. vol. i. p. 405. That the attrition of air will produce heat is very plain from an experiment already mentioned, and it seems not improbable that the motion of condensed air should raise a greater heat, which is a matter within the reach of experiment, and is worth inquiring into.

as an extemporaneous tinder-box; for it may be hammered on an anvil till it becomes red hot, and will fire a match of brimstone. A strong man, who strikes quick, and keeps turning the iron so that both sides may be equally exposed to the force of the hammer, will perform this in a less time than would be expected.

It is not necessary that the bodies with which the attrition is made should be very hard, as the plates of glass, the flint and the steel, the iron and the hammer: a cord rubbed backwards and forwards swiftly over a post or tree will take fire: a stick of wood pressed against another which is turned swiftly about in a lath, will soon make it turn black, and emit a smoke: and even the palms of the hands, when they are dry, and are rubbed briskly together, will smell as if they were scorched. The method of exciting fire by rubbing two sticks of wood together was anciently practised by country people, and is still retained in some parts of the world. Seneca, in his Natural Question, gives this account of it: *fieri solet ignis duobus modis; uno si excitatur, sicut ex lapide percusso: altero si* attritu *invenitur, sicut cum duo ligna inter se diutius trita sunt. Non omnis*

omnis tibi hoc materia præstabit, sed idonea eliciendis ignibus; sicut laurus *hederæ, et alia in hunc usum nota pastoribus**. "Fire is "obtained by two different methods: the "first is by striking it out of stone; the "other, when it is found by attrition, as "when two pieces of wood are rubbed for "some time together. But all wood is not "fit for this purpose, only such as is dis-"posed to yield fire, as the bay tree†, the "ivy, and others which are known by the "shepherds to be proper for this use."

Pliny mentions the same practice, and says, *nihil hederâ præstantius, quæ teratur lauro, laurumque terat*‡. But it appears from a passage in Festus Pompeius, that this was effected not by every simple attrition, but particularly by terebration§; and this agrees with

* Nat. Quæst. lib. ii. cap. 22.

† I think there is little or no doubt that the bay-tree is the *laurus* of the ancients; the inflammability of which is so particularly mentioned by Lucretius,

> Nec res ulla magis quam, Phœbi Delphica laurus
> Terribili sonitu flamma crepitante crematur.

‡ Lib. xvi. cap. 40.

§ Lib. ix. Mos erat tabulam felicis materiæ tandiu terebrare, quousque exceptum ignem cribro æneo Virgo in ædem ferret.

with the more modern account of Marcgravius, in his History of Brasil*. The fact is so authenticated, that we cannot dispute it, and the principle of raising fire by attrition is agreeable to nature; all the difficulty lies in understanding the dexterity necessary to perform it by a manual operation, and in choosing the sort of wood with which it is most likely to succeed. The manner is exactly described in Captain Cooke's Voyage†, but the wood is not ascertained. The inhabitants of New Holland are there said to "produce fire with great facility, and spread "it in a wonderful manner. To produce it "they take two pieces of dry *soft* wood; "one is a stick about eight or nine inches "long, the other piece is flat. The stick "they shape into an obtuse point at one "end, and pressing it upon the other, turn "it nimbly, by holding it between both their "hands, as we do a chocolate mill, often "shifting

* Frustum ligni, aut potius radicis hujus arboris (ambaibæ) sumunt exsiccatum; in eo faciunt foraminulum; huic immittunt bacillum fastigiatum ex duro aliquo ligno, et quasi terebrando circumagunt, pedibus frustum illud immotum detinentes, ac applicantes folia sicca arborum, seu gossipium: sic eliciunt ignem prout libet. lib. iii. cap. 1.

† See Hawksworth's Collection, vol. iii. cap. 8.

"shifting their hands up, and then moving "them down upon it, to increase the pres-"sure as much as possible. By this me-"thod they get fire in less than two minutes; "and from the smallest spark they increase "it with great speed and dexterity." Thus stands the fact: but the compiler has added a reflexion, in which I cannot agree with him: "There are perhaps few things (says "he) in the history of mankind more ex-"traordinary than the discovery and appli-"cation of fire. It will scarcely be disputed "that the manner of producing it, whether "by collision or attrition, was discovered by "chance:—these circumstances considered, "how men became sufficiently familiar with "it to render it useful, seems to be a pro-"blem very difficult to solve." This and what follows might have passed very well as the speculation of a New Hollander; and we are not surprised if it occurs in the Fasti of Ovid, an Heathen writer:

> " ——— saxis pastores saxa feribant,
> " Scintillam subito prosiluisse ferunt.
> " Prima quidem periit, stipulis excepta secunda est;
> " Hoc argumentum flamma palilis habet."

But that people in a christian, civilized, philosophical country, whom Providence hath blessed

blessed with a knowledge of the true origination of mankind, and their earliest history, should condescend to such poor conjectures, is a symptom of present infidelity and approaching barbarism. The first family placed by the Creator upon this earth offered sacrifices; which being an article of religious duty, they were certainly possessed of the means of performing it, and consequently of the knowledge and use of fire, without which it could not be practised. The next generation presents us with artificers in brass and iron, which could not possibly be wrought without the complete knowledge of fire; neither indeed could any works of art be well carried on. The account of this affair in the Bible is much more natural, because it is more agreeable to the goodness of God, and the dignity of the human species, than to suppose, on the principles of a wild and savage philosophy, that men were left ignorant of the use of an element intended for their accommodation and support. To interdict a man from the use of fire and water, was accounted the same in effect as to send him out of life; so that if men, upon the original terms of their creation, were thus interdicted by the Creator himself, as the heathen

heathen mythologists supposed them to be, they were sent into life upon such terms as others were sent out of it. If we admit any one such gloomy supposition, where shall we stop? If mankind were left destitute in respect to the knowledge of fire, perhaps they were left without language, without food, without clothing, without reason, and in a worse condition than the beasts, who are born with the proper knowledge of life, but man receives it by education; therefore he who taught the beasts by instinct, taught man by information. This digression having a near relation to our present subject, and particularly to this part of it, the reader, I hope, will excuse me for going into it. If the knowledge of fire could ever possibly be lost by any people of the earth, degenerating into gross stupidity and barbarism, it is not impossible that time and chance might recover it, though these are but very indifferent principles to trust to. Gunpowder was discovered, as we say, by chance; but mankind had spent above five thousand years on earth before they fell upon it. Sanchoniatho, in his Phœnician History, relates a circumstance of trees taking fire when their branches were rubbed together with the wind:

and

and Avicenna, the Arabian physician, tells us, that a sort of cane, which the Indians use for their lances, has been set on fire, when the canes, while growing and very dry, were rubbed hard one against another with the violence of the wind *. In some parts of the globe fire offers itself spontaneously to the use of man, as at Baku in Persia, where naptha takes fire of itself from the ground, and is applied by the inhabitants to domestic purposes †.

Fire will manifest itself without being excited either by percussion or attrition: a burning heat frequently arises from cold materials in such masses of matter as consist of heterogeneous principles combined together. If a large quantity of hay is laid together in too moist a state, it will by degrees take fire, which seems to happen for the following obvious reasons: it is certain that the subtile matter of fire is at all times circulating through the porous substance of bodies, and expelling the moisture which is lodged within them, in the form of vapour, which is sometimes visible, but in many cases so slowly excited as to be invisible, like the insensible

* Phil. Trans. vol. lvii. N°. II.

† See Mr. Hanway's Travels.

perspiration of the animal frame. This vapour being excited within the recesses of the mass, and being unable to escape through the pores of the incumbent matter, so fast as it arises, it is returned back upon itself, and its agitation is thereby very much increased, the natural consequence of which is an attrition of the parts, producing an intestine heat. At the same time, a large quantity of air is generated, which adds much to the expansive force; and while these causes are at work, the whole matter is sinking with its own weight into a lesser compass, by means of which the fire and air being strongly compressed, are excited still to farther degrees of commotion, till they break out into actual flame, and consume the substance. The pressure of the air and vapour from the incumbent weight, has a great share in this effect. When loose gunpowder is fired, it is easily dissipated with little explosion, and may almost be said to evaporate; but when it is confined and compressed, the force of the explosion is very much increased; and the case is much the same when the vapour of boiling water is confined: from which examples, it is easy to imagine what a commotion will arise, when the steam of ferment-

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ing vegetables is strongly compressed. What happens to a stack of hay, will also happen to an heap of coals, when they are laid up too moist in a very large quantity, and in a close place. An intestine heat will be raised, breaking out at length into an actual fire. From the great quantity of the fuel, so intense is the heat when a large stack of hay is on fire, that the substance of the hay is turned into glass. I have some lumps of this vitrified matter, with the stalks of hay appearing in some parts of them like the needles of antimony; they were found among those ashes that fell from the heart of the fire, after a conflagration, in which forty loads were consumed *.

We have another way of obtaining fire, by exciting it to activity in such bodies as retain it long in a fixt or quiescent state. There are many of these, and of different sorts, some solid, some fluid, some natural, some artificial; all of which may be called phosphori, or substances retaining the matter of light within them, as the sponge retains water. Some phosphori are very conspicuous, others obscure and almost equivocal,

* The same effect is related in the Dissertationes Physicæ of Paulus Casatus, the Venetian. Diss. 7. p. 212.

of which latter sort are oils, sulphurs, and such bodies as are of a combustible nature, by abounding with phlogiston, the matter of inflammability. From these bodies fire may be raised many different ways.

Iron filings, and powdered sulphur, mixed together in equal quantities to the weight of fifty pounds, and made up into a paste with water, will in a few hours acquire a very great heat, and if the mixture is confined in a close vessel, it will take fire and explode. The experiment is sometimes made by confining these ingredients under ground, and ramming the earth hard over them, to illustrate the doctrine of volcanos and earthquakes, which may reasonably be supposed to arise from subterraneous magazines of sulphur and the ore of iron, raised to a fermentation by the accession of water, and acquiring an immense force from the compression of their heated vapour under an incumbent weight of earth, especially when the materials are lodged deep in the bowels of the earth. This is confirmed by the kind of matter which is cast out of volcanos; their lava, or melted mineral matter, seeming to be chiefly composed of iron and sulphur.

The industry of the chemists led them to the

the discovery of an extraordinary substance, made of the putrid juices of animals, deprived of their volatile parts, and urged with the most vehement heat of a reverberatory furnace. The matter which then comes over is unctuous and solid like wax, and so strongly impregnated with the matter of fire, that it will burn away in the air with a penetrating urinous smell; but if it is secured from the air, by being laid under water, its fire will there keep cold for many years, and be as vigorous on occasion as it was at first. I know not what to call this but a kind of unctuous lime, or sulphur, rendered more open and active by a smoking spirit of salt. The oil and sulphur of this strange substance will not permit the water to have any effect upon it, but that of protecting it from the air. I have preserved a small piece of this phosphorus in a phial of water for above twenty years; it was not more than an inch long at first, nor thicker than the small end of a tobacco-pipe; yet it has furnished me with matter for many experiments, and there is enough of it still left for many more. The words which are written with it upon paper will shine in the dark like the light of a glow-worm, and last for half an hour; when they

begin to fail, a blast of air will excite them afresh, and if they are presented near to a fire, they become exceedingly vivid, and will scorch the paper. If a small particle is laid upon coarse paper, and rubbed swiftly over with the flat side of the blade of a knife, it will instantly set fire to the paper, and break out into a bright flame; than which there is no experiment better adapted to shew the effect of attrition upon the matter of fire *.

There

* More particulars concerning this body may be learned from the chemical writers. The following account is extracted from Macquer, one of the most sensible and ingenious modern writers on chemistry. "From the marine "acid combined with the phlogiston results a kind of sulphur, differing from the common sort in many respects, "but particularly in this property, that it takes fire of itself, upon being exposed to the open air. This combination is called English phosphorus, or phosphorus of urine, "because it is generally prepared from urine. This combination of the marine acid, with the phlogiston, is not easily effected, because it requires a difficult operation in "peculiar vessels. For these reasons it does not always "succeed; and phosphorus is so scarce and dear, that hitherto chemists have not been able to make on it the experiments necessary to discover all its properties.—Phosphorus resembles sulphur in several of its properties; it "is soluble in oils; it melts with a gentle heat; it is very "combustible; it burns without producing soot, and its

"flame

There is another kind of phosphorus prepared from a mixture of powdered alum and wheat flour, which are ustulated in an open vessel, but not quite reduced to a calx, then put into phials close stopt and coated with clay, and kept for some time in an intense heat, but not so long as to burn away the sulphur. If the phials are opened when quite cold, the matter will instantly take fire with the air, and burn away with a sulphureous smell.

It is also possible to excite fire by the mixture

" flame is vivid and blueish." vol. I. chap. iv. § 3. The same author has extracted from Mr. Hellot, a Member of the Academy of Sciences at Paris, the whole process for making the phosphorus of urine, in which there are many curious and wonderful circumstances; but the account is too large to be given in this place. The first person that hit upon phosphorus was Brandt, a citizen of Hamburgh, who worked upon urine with the hope of finding the philosopher's stone. The operation (when the material was known) was also discovered by Kunkel, and our Mr. Boyle. M. Margraaf of the Academy of Sciences at Berlin, discovered a way of contracting the operation, so as to produce the phosphorus in four hours. After many critical observations on the substance, he imputes its property in a great measure to a subtile vitrifiable earth combined with the other principles. See Macquer's Elements of Chemistry, part I. chap. iii, process 2.

ture of two cold fluids; the one a lean, hungry, penetrating acid, distilled from oil of vitriol (as it is commonly called) and saltpetre, the other a rich and ponderous vegetable oil abounding with sulphur; so that the mixture of these two forms a kind of fluid gunpowder. The ingredients of gunpowder being solid and sluggish of themselves, must be put into action by the contact of fire already excited; but these fluid ingredients are driven so forcibly into each other, that the bare mixture produces a collision sufficient to kindle an actual flame, which the materials support till they are burned away, and nothing is left behind but a black crust or cinder. The two fluids most proper for this experiment are oil of sassafras, or oil of cloves, and the strong spirit of nitre above mentioned. Sir Isaac Newton describes the extraordinary effect of these two fluids when mixed together in a small quantity in vacuo. "When a drachm of the "above-mentioned compound spirit of nitre "was poured upon half a drachm of oil of "caraway seeds in vacuo, the mixture imme-"diately made a flash like gunpowder, and "burst the exhausted receiver, which was

"a

"a glass six inches wide and eight inches "deep*." The accension is quicker and more violent in vacuo, because the aerial and fiery particles which explode together are more easily disengaged from the body of the conflicting fluids, when they are not compressed and confined by the incumbent air.

It was a prevailing opinion with the ancients, that fire might be excited by the swift passage of a projectile through the air; and the poets accordingly tell us that leaden bullets have been melted, and arrows have been set on fire in their flight. It does not appear that any thing of this kind is possible in nature: that the descriptions of the poets are hyperbolical and fictitious, is certain; because we do not discover that bodies are either liquified or inflamed by flying two thousand feet in a second of a minute, which is a much swifter motion than could be given by their engines to any missile weapon. Modern philosophers have indeed asserted that a cannon bullet acquires a considerable heat from the mere attrition of the air against its surface. Boerhaave adopts this notion, but Muschenbroek denies it, imputing all the heat that is found in the ball after its flight

* Opt. p. 354.

flight to the forcible flame of the gunpowder acting upon it before it is discharged from the mouth of the piece. If this be so; if the ball derives all its heat from the gunpowder, and none from the air through which it flies, it is somewhat extraordinary that the ancients, whose projectiles were never previously heated by gunpowder, should have been so strongly possessed with this opinion. Boerhaave affirms, that the time is too short to admit of the communication of any sensible heat from the powder: and I am rather inclined to believe that if the experiment were to be tried, a candle of tallow, or a small part of it, discharged from a musket, would be secured by the interposed wadding from the effect of the flame; whereas the candle ought to be melted by an heat sufficient to make an impression upon iron or lead. When a bullet hath struck an object, and is flattened by the blow, it is certainly very hot: but in this case the internal parts are rubbed swiftly and with great force over one another, on which circumstance the conception of heat and fire seems chiefly to depend. But when a ball flies through the air, the internal parts preserve the same situation, and remain at rest; so that the action of a fluid

fluid against the surface, and that only against the lesser half of it, does not seem capable of producing any great effect; and therefore, upon the whole, we cannot judge it probable that actual fire should ever have been excited upon this principle.

Of the Manner in which Fire is supported.

Pure elementary fire is dissipated as fast as it is collected, unless it has some matter to reside in, which we call fuel. The fire at the focus of a burning-glass, how intense soever it may be, vanishes instantly when the glass is removed. In order to detain and support it so as to establish a permanent source or circulation of fire in the same place, it is necessary, first, that the fire reside in some solid or fluid matter; secondly, that the air be freely admitted to it.

No fuel is apt to conceive or retain fire, unless it is impregnated with oil or sulphur; which two are very nearly allied in power, though very different in outward appearance; sulphur being a brittle solid oil, and oil a fluid sort of sulphur. Each of these derive their activity from the fire that is combined

bined

bined in a quiescent state with their other principles; and which in the act of burning is set at liberty, when the parts of the burning body are decomposed. Pitch, resin, camphor, are oils of different degrees of purity in a solid form, and all capable of sending up a dense unctuous smoke when they are set on fire. Wood and sea-coal are no otherwise inflammable, than as they contain an oily or unctuous principle. When this is burned away, a body may be ignited, or made red-hot, by the forcible action of fire, but it can no longer be inflamed. When it is said that fire escapes in the decomposition of bodies during the act of burning; it is incredible, and therefore should not be imagined, that the whole quantity of fire diffused through the air from a burning body is all derived from its own store. No effect can be greater than its cause, neither can any thing in nature give, but so far only as it receives. It is plain there is such a thing in the world as perennial inconsumable fuel; but such a phænomenon is impossible, in the nature of things, unless we suppose a circulation; so that the source which emits fire may receive something equivalent at the same

same time, and with this condition it is easy to understand that the action of burning may be perpetuated.

When fire begins to act upon fuel, it drives out the water, the volatile salts, and the oils, contained within it, in the form of smoke: and the smoke, when sufficiently unctuous, takes fire and turns into flame, which hovers over a burning body so long as the unctuous vapour rises up to support it. That flame is nothing but smoke on fire, may be shewn by a very simple experiment. When a candle is extinguished by a blast of the breath, a dense smoke rises up from the wick, which will catch fire, if the flame of another candle be held over it at some little distance. When the column of the ascending smoke touches the flame, it is rekindled, and a flame is propagated down the column, which soon seats itself upon the extinguished candle. Hence it follows that none but volatile materials can be inflammable; and that the most volatile will consequently be the most inflammable; which is the case with turpentine, camphor, and naptha, and the vapour of spiritous liquors. Boerhaave, in his Chemistry*, describes two instruments which shew the inflammability

* Vol. I. p. 309.

flammability of smoke in a more elaborate and elegant manner, by driving the smoke which arises from the fuel back again through the body of the fire: but as the kindled smoke of an extinguished candle shews the same thing in a manner not less satisfactory, I forbear to describe them particularly.

Distilled spirits are inflammable, like oil; which is the less to be wondered at, because they are strongly impregnated with fire when they are raised from their subjects; and this latent fire betrays itself in their taste: nay, the matters themselves from which they are raised must first have undergone some alteration from the action of fire in fermentation; otherwise they will not yield any spirit.

The more oil there is in any wood, the fitter it is for fuel: whence the wood of fir or deal, which is impregnated with turpentine, is extremely inflammable, and burns with a white vivid flame. So likewise the evergreens, which abound with a ponderous oil, will flame much; and the watery humidity intermixt with their oil, is soon rarefied, and explodes much as it burns; the burning oil soon communicating to it an heat superior to that of boiling water, so that it is violently disengaged from the oil and dissipated in the

form of steam. When wood is decayed and rotten, it is destitute in a great measure of its oily principle, and is therefore no longer inflammable, but will grow red hot and fall away into ashes. This is the case with what we call touchwood; which, on account of its dryness and porosity, is very susceptible of fire, but burns slowly away without emitting any flame. Charcoal is a quick and strong fuel, because the moisture is all expelled, and the substance is left very porous, and consequently accessible to the fire. The volatile oily parts being also excited within the wood by the heat, and hindered from flying off by an incumbent mass of dust, sand, and ashes, are spread over the earthy parts, and exposed naked to the immediate action of the fire. All the sap being expelled from this fuel, its smoke is much more subtile and penetrating than that of common wood. Its pernicious effect upon the lungs hath appeared in so many unhappy instances, and is now so generally known, that it is scarcely necessary to add a caution against it. Here it is worth observing, that all white bodies resist the effect of light by reflecting it away from them; but when the same bodies are made black, they absorb the rays,

and are much sooner heated. It is the same with respect to the act of ignition; and therefore it is the nature of fire to turn bodies black before it inflames them. The sudden kindling of gunpowder by a spark of fire is owing to the blackness of the charcoal dust, which is always mixed up with the other ingredients for this purpose. The blackness arises from the oil of the wood, which being thrown to the surface, is there scorched by heat, and made susceptible of fire from every spark that touches it.

Several other particulars concerning the nature of fuel will occur to us, if we now attend to the second condition requisite to the establishing a permanent source of fire; which is a free admission of the element of air. To show how absolutely necessary this is to the support of fire in any kind of fuel, we need only take a bright burning coal of wood or charcoal, and plunge it suddenly into a vessel of the most highly rectified spirit of wine, than which no liquor in the world is more inflammable, except the *spiritus ætherius vinosus*, known to the chemists by the name of *æther*. The coal thus suddenly immersed will neither give fire to the spirit, nor retain the fire it brought with it,

but

but is quenched as effectually as if it had been plunged in water. If another coal be taken, and only dipped in the spirit, so that part of it remains above the surface, the spirit will then catch fire: but still the flame will confine itself to the surface, acting only on those parts of the fluid which are immediately contiguous to the air. When fire is excited in any solid earthy matter, as in a live coal of wood, or in a mass of heated iron, it is capable of a red, or even of a white and glowing splendor; but does not assume the shining appearance of flame, unless the inflammable parts of the fuel are raised aloft and diffused in the form of vapour, so that the air has free access on every side, and can penetrate into the body of it. It is for this reason that all inflammable matter is so dangerous, when it subsists in the form of a thin invisible vapour; for it is unexpectedly kindled by the contact of fire, and its texture is so loose that the air penetrates it and propagates a flame throughout the whole extent of it in a moment. The sulphureous steams with which the air is apt to be charged in mines, are frequently fired by a candle, and explode with very dreadful effects. But there is this singular difference between the com-

combustible matter of gunpowder, and the inflammable fire-damps in subterraneous caverns, that the former will not be fired by flame but slowly and with difficulty; the latter will not be fired by a spark: and therefore in such works as are subject to the danger of fire-damps, they work by the light of a machine which yields sparks of fire by attrition. Each of these combustible matters is kindled by that which is most congenial to itself: black and solid fuel takes fire from a spark; but such fuel as is fluid is most easily kindled by flame; and we may reckon all vapours among the class of fluids.

A common extinguisher placed over the flame of a candle, which is a very simple experiment, will shew how necessary the air is toward the support of fire in any fuel: for though the flame in this case is partly suffocated by the retention of its own smoke within the cavity of the extinguisher, yet doubtless the effect is principally owing to the exclusion of the air; to confirm which, we must place the candle under the receiver of an air pump, and if the vessel is not too large, the flame will disappear with the first stroke of the machine. When gunpowder itself, which in a manner carries its own air

along with it, is exposed to the focus of a burning glass in vacuo, the sulphur of the composition will melt and smoke faintly, but will not explode. On the other hand, it is universally known how fire is quickened and increased by a blast of air: on which account it is an established law of nature, that as soon as fire begins to spread itself, a stream of air rushes in from all sides to support it; and the larger the fire, the sharper is the indraught of air. In what manner air acts upon fire, so as to supply it continually with fresh life and vigour, is a question of great importance, and of some difficulty. At present I insist only on the fact, that air is necessary to the continuance of fire, and that the action of fire in general is the joint action of fire and air together. Between these two a double motion is maintained, of fire outwards, and of air inwards. That the matter of the fire goes outwards into the air, is evident from the shadow which any opaque body casts behind it, by intercepting this matter in its course: and the same is clear enough from the heat propagated through the air, and which at a considerable distance from the fire itself, will act as fire, and inflame bodies when it is reflected from a con-

 cave

cave speculum. The continual current of air is manifest to sense in the contrary direction. A silk handkerchief, or any other light body, held near a fire, will be carried into it; and the rushing of the air through all the joints and apertures of the doors and windows of a room, heated by a fire, may be heard and felt very sensibly.

It is chiefly owing to the concurrence of the air, that the matter of fuel is wasted and consumed to an heap of ashes. The consumption is very slow, and the fire will live a great while, if embers are raked together, and protected from the forcible impression of the air, by being covered up with their own ashes: this is a common way of preserving fire, to be excited occasionally for domestic uses. Charcoal inclosed in a box of iron, may be ignited for many hours in a strong fire, and when it is taken out will be found to have suffered little or no change. But if the same is set on fire, and the air admitted to it, its surface is very soon covered with a coat of ashes; and as this falls away another arises, till the whole substance is wasted, and nothing remains but a white powder, which is a mixture of incombustible earth and fixed salt. When a diamond is laid

laid in a naked fire, the polish is taken away from the surface; but when it is secured from the air, the fire makes no alteration in it.

There is a curious and elegant experiment to illustrate the vehement action of a blast of air upon fire and the parts of fuel. Some metals melt more easily than others; but iron is a metal which cannot be fused without the utmost violence of fire. Notwithstanding all this difficulty, let a bar of iron be laid in a smith's forge, till it has got what they call the white heat: when it is as bright and sparkling as it can be made, let it be taken out of the fire, and let a blast of air from a common pair of bellows be blown strongly against the heated extremify of the iron; which, instead of being cooled by the blast, will become more white and shining than before, till by degrees it rolls about in a liquid form, sending out brilliant sparks in all directions, and falling in frequent drops to the ground. A very considerable part of the rod may thus be liquefied and blown away before the bellows will lose their effect. If a cannon bullet is heated in the like manner, and a large pair of forge-bellows are applied, it affords a glorious spectacle, which can be

 conceived

conceived only by those who have seen it. The eyes are dazzled with the sight, as when we look upon the sun; which, indeed, it resembles more nearly than any other object experiments can exhibit to us.

This experiment was shewn several years ago by the ingenious Mr. Henry Horne, a master in the steel manufacture, to Martin Folkes, Esq. when he was President of the Royal Society, and to some other members with him. It is pity some notice was not taken of it in the philosophical collection of that learned body. The smiths, whose business lies at a forge, are so well acquainted with this effect of a blast of air against ignited iron, that they cautiously avoid exposing the metal too near to the nose of their bellows. A fire-man who is but green in his profession, is very apt to be catched with this accident from his bellows, by which he utterly spoils the stuff he works upon by giving it what they call the *wind-rot*.

We proceed now to investigate the principles on which fire is thus supported and invigorated by the concurrence of the air.

Some learned men have supposed, that as the air is impregnated with nitrous exhalations, which are of a combustible nature, they

they supply the fire with a refined sort of fuel: and that fresh air is continually necessary, because that air which has been in contact with the fire is thereby deprived of its nitrous principle, and so rendered effete and unfit for the purpose. But this solution does not correspond with the effect. Nitre, when it is burned, yields a factitious vapour, which has the appearance of air. When a piece of brown paper, dipped in a solution of nitre and then dried, is made to burn in a close vessel, it seems to increase the quantity of air. Therefore, if air feeds the flame of a candle because it is impregnated with nitre, a candle burning under a close vessel should rather increase the quantity of the air; but it is found to lessen it, as we shall see hereafter.

There are in fact three different principles on which fire is supported by air, all conspiring to the same end. First, the air, by its pressure, keeps the fire together in a body, and prevents its dissipation. By this effect of the air, the fire is concentrated, and its splendour is very much increased. When the electric spark explodes in air, it is extremely bright and vivid like lightning; but if the same is tried in the exhausted receiver,

instead of the spark and explosion, we have a silent stream of fire, much more faint and dilute. The fire with which boiling water is impregnated, escapes very easily *in vacuo*; and the water, in these circumstances, cools much faster, even in a warm room, than if it had been exposed out of doors in a frosty air, which demonstrates, that fire is confined within the body of the water, by the superficial weight and pressure of the air. The outline by which the flame of a candle is so well defined, is owing to some pressure which acts equally on every side; and this pressure can be no other than that of the air, which may be discovered by carrying the candle forward; in which case, the side of the flame that meets the air will be bright and well defined, while the side that follows will be ragged and more dilute.

The sight is so familiar, that we pay little regard to it; yet it is a matter of astonishment to reflect upon, that a fluid, so weak as fire might be supposed to be, on account of the infinite subtilty of its parts, should be expanded itself, and expand the air with all that force which experiment demonstrates. The medium near a fire is certainly much more refined than at some distance; and it

will be a very moderate supposition if we imagine the flame of a candle to be twice as rare at its superficies, as the common air of the atmosphere; whence it follows, that the atmosphere will there press upon it with half its force, that is, with a weight equal to seven pounds on every square inch. If there is a sphere of such flame, whose diameter is one foot, the air will compress its surface with a force equal to three thousand one hundred and sixty-four pounds; yet the fire maintains its dimensions with ease against a compressing power, which seems more than sufficient to drive it all back into its central point. This computation is a gross one, because it supposes a limit which does not really exist: it supposes that the air on the surface hath its whole density, while the air of the flame hath but half its density; however, the computation is the best the nature of the case will admit of.

Secondly, air, by its friction, increases the agitation of fire, and thereby raises the heat of it. If its friction against the ball of a thermometer is sufficient to stir up the included fire, and raise the thermometer, it must have a much greater effect of the same kind when the fire is naked and open, and the

the air can penetrate its very substance. When these two elements meet, the conflict must needs be very great. The air is naturally impelled in a direction toward the centre of the fire, and being there expanded, a considerable part of it is driven upwards by the pressure of that which succeeds; and during all this, the quantity of the fire continually increases with an expansive motion outwards; so that between these two contrary motions, the agitation of the parts of fire, by the friction of the air, must be very great.

But thirdly, experiment shews us, that the ancients were right in the opinion they universally maintained, that air supports fire as a *pabulum;* that is, that it actually parts with some of its substance to supply fresh matter, increase the fire by being itself attenuated and refined into the condition of fire. However violent the action of air upon fire may be, it is certain that fire must re-act equally upon air, by the common laws of the Newtonian philosophy. Let us suppose the rays of light to diverge after their manner from a burning point; if they move in right lines, they form an infinite number of angles which meet in the point from whence they proceed.

proceed. When the air enters and mixes with these diverging rays, the nearer it approaches to the centre, the more it compresses the fire, and is consequently compressed by it. In this conflict the fire is increased, and the air is diminished. The former of these is so well known, that it is superfluous to prove it; the latter will be evident from experiments.

"I set a lighted tallow candle" (says the ingenious Dr. Hales) "about $\frac{6}{10}$ of an inch "diameter, under the inverted receiver *zzaa* "(plate I. fig. 3) and with a syphon I im- "mediately drew the water up to *zz*. Then "drawing out the syphon, the water would "descend for a quarter of a minute, and "after that ascend, notwithstanding the "candle continued burning, and heating "the air for near three minutes. It was ob- "servable, in this experiment, that the sur- "face of the water *zz* did not ascend with "an equal progression, but would be some- "times stationary; and it would sometimes "move with a slow, and sometimes with an "accelerated motion; but the denser the "fumes, the faster it ascended. As soon "as the candle was out, I marked the height "of the water above *zz*, which difference

"was

"was equal to the quantity of air, whose "elasticity was destroyed by the burning "candle. As the air cooled and condensed "in the receiver, the water would continue "rising above that mark, not only till all "was cool, but for twenty or thirty hours "after that; which height is kept, though "it stood many days; which shews that the "air did not recover the elasticity which it "had lost. The event was the same when, "for greater accuracy, I repeated this ex-"periment by lighting the candle under the "receiver with a burning glass. The ca-"pacity of the vessel above *zz*, in which "the candle burned in my experiment was "equal to 2024 cubic inches; and the elas-"ticity of the $\frac{1}{28}$ part of this air was de-"stroyed *." The like experiment had been made before, and is mentioned by other authors, to one of whom Dr. Hales has referred us.

I have made many experiments of this kind myself with glass vessels of different capacities, which sometimes had a mercurial gage adapted to them, and sometimes a water gage to shew the progress more minutely. I usually proceeded, as Dr. Hales did, in the former

* Hales's Veg. Stat. p. 230.

former of his methods, by placing the vessel as expeditiously as possible over the matters already kindled. I found that a red-hot iron would have the same effect with a flaming candle, first depressing the gage, then raising it, in the whole about an inch and a half, so as to alter the density of the included air about $\frac{1}{20}$ part; for, the elasticity of air being as its density, we are to conclude, that if its elasticity is changed, its density is changed in the same degree. In this experiment it is to be noted, that the heated iron was of much larger dimensions than the flame of Dr. Hales's candle. With flaming spirit of wine the density has been lessened more than one half; with flaming spirit of turpentine, which sends up a dense black smoke, not quite so much. A piece of live charcoal raised the mercurial gage seven inches, reducing the density of the medium nearly one quarter, when a burning candle would raise it no more than three inches; but this difference proceeded from the long continuance of the fire in the charcoal, which yielding little or no smoke, is not so soon suffocated with the return of its own vapours*. After many

* I made these experiments twenty years ago. The experiment

many trials I could not find that there is any effect in sulphur superior to other fuel, but rather inferior, particularly to charcoal, and rectified spirit of wine; and upon the whole, it appeared, that the larger and quicker the fire, (in equal spaces,) let the fuel be what it will, the greater is the consumption of air; so that though different sorts of fuel may occasion some critical differences, the general effect is from the fire, and not from the fuel.

And now the question is, how we are to determine upon this effect? An experiment in Nature, like a text in the Bible, is capable of different interpretations, according to the preconceptions of the interpreter. The advocates for a nitrous vivifying spirit in the air, different from the air itself, suppose this spirit to be the proper pabulum of fire, and that air will no longer feed fire when this is extracted: but what this can have to do with the elasticity does not appear, because it ought to be rather more than less after the deflagration of nitre; so that if this spirit is admitted, though it seems a creature of the

periment on charcoal has lately been repeated in a better manner by another hand; with a glass inverted into a pool of mercury.

the imagination, it will not lessen the difficulty.

The next solution is that of Dr. Hales, who supposes the elasticity of the air to be destroyed, and that the fumes or vapours of burning matter absorb it; in which we seem to have two solutions instead of one, and these not very consistent with each other. For if any of the air is absorbed, then there is a loss of substance in the air; and if the density of what remains is less, no wonder if the elasticity is less also, because it is always as the density. To say that the elasticity is destroyed, is to suppose that the elasticity is different, while the density is the same. That smoke and vapours may have some subtile effect in changing the texture or condition of the air is very possible, but they are by no means adequate to the phænomenon, which does not follow the fumes, but the fire. The clearest matter will have the same effect as the most fuliginous; and the fire of sulphur, which emits the sharpest of all fumes, and such as have been supposed to affect the elasticity of the air in a peculiar manner, acts only as common fire, with no extraordinary effect from its vapour.

We must therefore look for some other third

third solution, and I can see none but this; that as the increase of fire is the diminution of air, what was the one becomes the other. And why not? Philosophers have never been backward in admitting transmutations, even beyond the limits of nature. Sir Isaac Newton was of opinion, that water turns into earth, and that acids, by acting on the parts of solid bodies, turn them into air *: but if there is any real transmutation in nature, we must find it between the elements of fire and air, which are undoubtedly homogeneous, and, when they operate together, surprize us with many new and unexpected appearances. This solution could not possibly occur to that very worthy and ingenious experimentalist, Dr. Hales, nor could have been admitted if it had occurred, so strongly was he attached to the qualities of attraction and repulsion, by which he accounted for every thing; and he likewise supposed fire to be no element, but an affection of bodies. Some little time before his death he became acquainted with some experiments and reasonings which represent nature in a different light, and was so ingenuous as to confess to a learned nobleman, from whom I had my information,

* See Hales's Veg. Stat. p. 291.

information, that "he found it would be "very hard to stand against the doctrine of "a plenum.

But to proceed with our subject: the candle in Dr. Hales's experiment, the flame of which might occupy, at the most, about half a cubic inch, consumed 78 cubic inches of air in less than three minutes, which is at the rate of 3744 cubic inches in a day, or 791 cubic feet in a year. If fires act according to their cubic dimensions, which is the nearest rule we can follow, then a fire of a cubic foot will consume 3456 times as much as the candle, that is, 2,733,696 cubic feet in a year. In London it is computed there are 170,000 dwelling-houses, and allowing only two such fires in an house, which is a very low reckoning, taking all fires one with another, and making no account of their numerous candles, the sum of cubic feet consumed by the fires of such a populous city as London in one year amounts to about 230 thousand millions of cubic feet: and if all other circumstances in different parts of the world, relating to this consumption of air, were taken into the account, I suppose the quantity we usually allow to the earth's atmosphere, would be found to be consumed

in a much shorter time than would be imagined; and that the air consumed in a course of years, if it were all collected together, would fill a sphere as big as the globe of the earth itself. Every intelligent reader will easily judge how hard it must be to collect the materials for such an unwieldy calculation as this is, with any tolerable accuracy; and therefore we must be content with a gross reckoning. The fact, however, will suggest some very obvious reflexions: first, that the daily consumption of air in a populous city must occasion an indraught of air from all the adjacent parts, so as to form sensible currents of wind, which will be much increased by the perpendicular ascent of the rarefied and lighter air, which will be constantly going off in upper currents, of a contrary direction to the lower air. All this may probably contribute more to keep such a place healthy, provided the passages are open enough to receive the benefit of the circulation, than all the noxious fumes that are raised there can do to infect the atmosphere, and render it unwholesome.

It will occur, secondly, that nature must have a stated mode of repairing this prodigious consumption; and whatever other ways there

there may be, we must suppose this to be one; that as fire consumes air, so air in its turn is recruited by a change of condition or coalescence in the parts of fire, and that there is a constant circulation in the world on this principle, so that the store can never be exhausted. It is well known that air is continually rising from the subterraneous regions in all parts of the world, as if the earth were a reservoir of air, as well as of water and minerals. All waters that come from the earth bring it with them, some more than others; and it is not improbable but that the waters of the sea, in circulating from vast depths, and being afterwards brought contiguous to the atmosphere, may part with it in great quantities. What effect the extreme dense air at great depths in the earth may have in arresting, compressing, and assimilating the matter of fire as it circulates through all the parts of the earth's body, it may be hard to prove; but it is natural to conceive, that as fire attenuates air, so air, under certain circumstances, may condense and assimilate the matter of fire. In short, if air and fire, like the serous and globular parts of the blood in the animal body, are convertible, by what subtile means soever

it may be brought about, many things very unaccountable at present will be more intelligible; therefore it is to be hoped, the relation between fire and air, which, like the blood in the body, are the life of nature, will be more attended to, and better understood. In regard to this subject, it is a fact well worth considering, that when calcareous and other substances yield such vast quantities of permanent elementary air in distillation, they are all opened by the matter of fire, which is undoubtedly combined with them in their elastic state: and if the fire that was attached to them evaporates and leaves them, they collapse, and lose their elasticity. Without the co-operation and association of this subtile element on such occasions, the apparent generation of expanded vapour would be a mystery and an impossibility.

It has always been known, that there is a striking relation between the flame of a candle, and the principle of life in the animal body. Physicians have argued for what some of them call a θερμον εμφυτον, an *innate heat;* others the *flammula cordis*, or a *biolychnus* (a candle of life) in the blood. Bartholine says, the animal fire is kept up in the

heart by a reciprocal ventilation from the lungs, as a common flame is excited by the air from a pair of bellows; and that when this ventilation from the lungs ceases, life goes out as naturally as a fire without air. The parallel is curious, and has a foundation in nature. It is very certain, that flame and animal life are both of them supported by air; that the same mephitic or stagnant air which puts out a candle, extinguishes animal life; that the air, which is too much rarefied to keep a candle burning, is insufficient for respiration; and, lastly, which is the most to our present purpose, that the animal fire, like the flame of a candle, reacts in like manner upon the air that supports it, by lessening the quantity, and that we always breathe out less air than we draw in. An animal inclosed within a glass vessel will live for a considerable time, but is found all the while to consume the air by its respiration, and expire nearly at the same state of the medium in which a light would be extinguished: hence it appears, that a part of the air in the act of breathing is attached to the blood, and probably assimilated by the gradual effects of the internal heat and vital motions. The remainder which is emit-

ed, is impregnated with an excrementitious vapour, which is as noxious when it returns upon the lungs, as the smoke when it returns upon a flame. The ancients had an opinion, that part of the air drawn in by the lungs, actually passes into the arteries, which may be looked upon as a continuation of the trachea; and the arteries are supposed to take their name from the air or spirit which they contain along with the arterial blood.

All observations in philosophy should be applied as much as possible to the benefit of man, the only philosophical, as well as the only religious animal. From the consumption of one part of the air in respiration, and the corruption of the remainder by the excrementitious perspirable matter of the blood and humours, we should be cautious how we accustom ourselves to a small close room, that we may have a free and fresh air to breathe in. The luxury and effeminacy of this age is studious to stop up every crack, and exclude as much as may be every breath of air, weakly consulting present indulgence, to the neglect of future ease and comfort. Children and young persons are more susceptible of the ill effect of a close air, and shew it by turning sick, and complaining of

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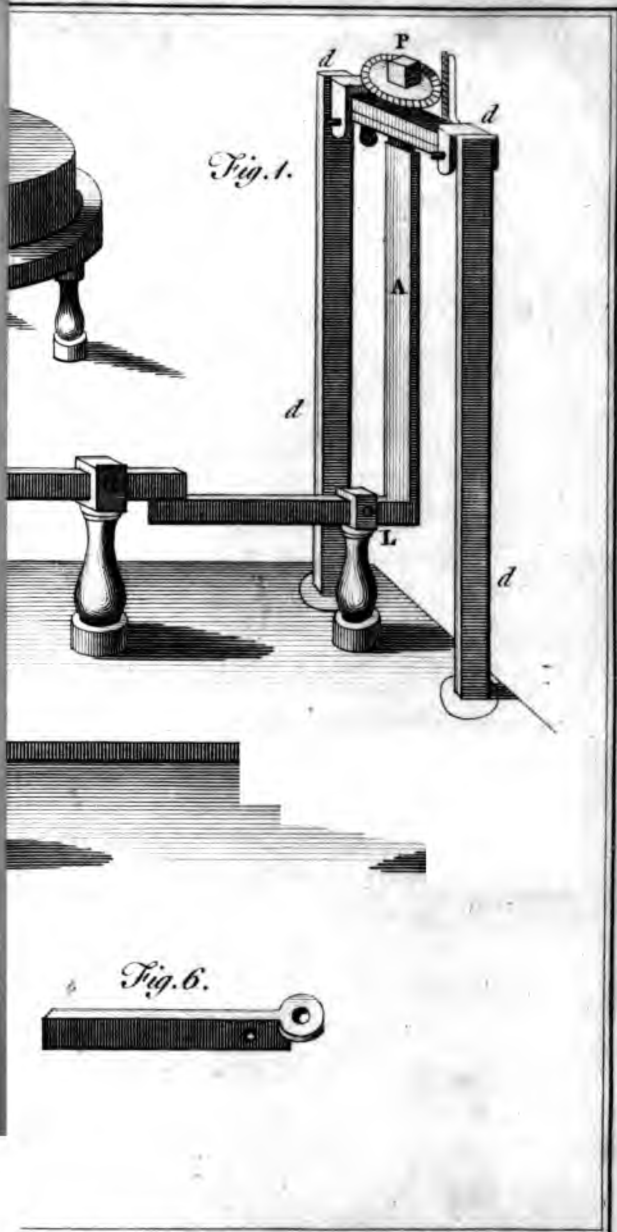
the headach: and they who by practice feel less present inconvenience, are slowly losing their complexions, (to be repaired afterwards by painting,) and destroying their constitutions, which are never more invigorated than by the coldness and purity of the morning air. It is a common observation, and a very true one, that the body is strongest, and the spirits most active, in sharp frosty weather, when fires burn the brightest: therefore wise people will be forward to expose themselves to the freshness of a cool air, that they may have the use and enjoyment of their faculties; while in others, the powers of life are fading away with the debilitating sleep of the morning hours, and the sickly warmth of a close apartment.

Experiments preparatory to the constructing of a new and more extensive Scale of the Degrees of Heat and Cold.

THE absolute degree of heat in burning fuel, or a red-hot iron, was what I had long desired to find, as being necessary to the natural history of fire; but I despaired of obtaining it with sufficient accuracy, till in making some trials with the pyrometrical machine, described in the former part of this discourse, it occurred to me, that the instrument might be applied with advantage as a thermometer of large extent, if I could but reduce the value of its motion to the ordinary scale of Fahrenheit.

For this purpose, the bar A, (see plate II, fig. 1.) included in the brass essay-box or tube, was heated together with a mercurial thermometer by the application of boiling water; and when it appeared by the index that the bar had acquired as much heat as the water would communicate, the heat of the water was at the same time marked by the thermometer. And thus it was discovered what number of degrees in the graduated



Jn.° Lodge Sculp.

duated arch HI answered to a certain number of degrees in Fahrenheit's scale. The motion of the index could not be equable in all parts of the arch; yet its irregularities were proved, and the proper reductions made by the micrometer, or graduated plate and screw expressed in the figure at P.

The next step was to find some of the higher degrees of heat by the expansion of my bars of brass and iron. Two substantial iron heaters, (fig. 4.) made red-hot, were applied in their turns to the bar under examination: and thus the degrees of heat, at which the several colours appear on the polished surfaces of brass and iron, were readily obtained. The great difference between the expandibility of these two metals was very manifest on this occasion; the brass, by the mean of several trials, being as 66, and the iron only as 35. But this method would not carry me near so far as I wanted to proceed in the prosecution of this inquiry; for, when the bar of iron, whose expansion was by much the lesser, had a moderate red heat, a greater extent was required than my instrument would admit of. After some reflexion another method of finding the degrees of heat occurred to me, which was very simple, and proved

proved sufficient in practice for all the purposes I had in view.

Dense fluids acquire heat sooner than rare ones. Water heats mercury more and quicker than mercury heats water. It is evident to sight how soon heat is communicated to a dense fluid, when a thermometer filled with spirits and another filled with mercury are placed in the same vessel of hot water. The spirits move very sluggishly, but the mercury in a very little time acquires its greatest expansion. This is still more evident when an heated iron is plunged into an open vessel of mercury; for if the iron is suddenly agitated under the surface of the mercury, all the heat it is capable of receiving is communicated to it almost instantaneously. This appeared to me long ago in the experiments described at p. 274 of my Essay on the first Principles of Natural Philosophy.

The method I am now about to describe is founded on the following principle: that the heats *communicated* to a given quantity of mercury by an immersion of the same iron differently heated, will be to each other as the *original* heats in the iron itself; and thus, when the communicated heats are known, the original heats may be found by them:

them; which is the solution of our present problem. For the application of this principle we must have some given proportion to work with: and we obtain it by taking any quantity of mercury convenient for the purpose, and plunging into it a piece of iron with a known degree of heat, to observe what heat it communicates to the mercury. Let us suppose the quantity of mercury to be 2 pounds, in an iron vessel; the heated iron, a cylinder weighing 274 grains: this cylinder having the heat of boiling water, which is 212 degrees, plunged into mercury having a temperature of 52 degrees, will communicate to it 10 degrees of heat, which is $\frac{1}{16}$ of the excess it had acquired. We say then, that let the excess of heat in the iron be what it will, the heat communicated to the mercury will always be $\frac{1}{16}$ of that excess: so that if we put t for the natural temperature of the mercury, h for the heat communicated, and x for the heat required, it will be $t \times 16h = x$. If, instead of boiling water, linseed oil is used, which takes a much greater heat, and a mercurial thermometer be applied with an unsealed tube, the proportion for the communicated heat may be found still more exactly.

This

This method was so easy in practice, that it seemed preferable to every other: and it added to my satisfaction that I found the other method by the heated iron bar of the machine agree well with this, so far as it extended. The colours of iron, and some of the nicer experiments on metals in fusion, were made by laying a rectangular piece of polished iron, of an equal thickness throughout, on the circular heater, which is represented upon its stand of brass in fig. 3. In all these experiments it is taken for granted, that the heated iron parts with all its excess of heat to the mercury; and that the distribution is so nearly instantaneous, that it may be taken for such without any màterial error. Some little time will inevitably be lost; and, therefore, the heats taken by this method of mercurial immersion, especially the greater heats near the extremity of the scale, which evaporate with rapidity the moment they are exposed to the air, will always be rather under than over-rated.

In constructing a scale of heat from these experiments, I adjust the value of my degrees to Fahrenheit's scale, in which 0 expresses the cold of Iceland, 32 the freezing point, 212 the ordinary point of boiling water. There

There is this inconvenience in it, that when we get below the cold of Iceland the scale is negative: but this is no great matter; the articles in that part of the scale are as yet but very few; and therefore it is better to let it go so, than make confusion by introducing a new reckoning. The experiments made by the philosophers at Petersburgh for discovering the cold of freezing mercury, were either so ambiguous in themselves, or are so loosely described by them in the Philosophical Transactions, that I could wish we had a more authentic foundation to proceed upon. Till this can be obtained, we must content ourselves with the present.

THE SCALE.

No		Negative.
1.	Mercury freezes	350
2.	Spirit of wine freezes	52
3.	Snow with strong spirit of nitre once mixed	25
4.	Snow with common sea-salt	6
5.	Cold of Iceland	0
		Affirmative.
6.	Port wine freezes	15
7.	Very hard frost in England	16
8.	Strong beer freezes	23
9.	Water begins to freeze	32
10.	Temperate air	55
11.	Summer air	76
12.	Alcohol boils in vacuo	77

13. Hottest

N°		Affirmative.
13.	Hottest air of England	86
14.	Water boils in vacuo	95
15.	Heat of human blood	96
16.	Heat of Bengal	105
17.	Heat of the Siroco wind, at Palermo in Sicily	112
18.	Greatest heat of a bath which the hand can well bear	114
19.	Bees-wax melts	145
20.	Alcohol boils	176
21.	One pound of water (of 52 degrees) to half a pound of fresh chalk lime	182
22.	One ounce of water (of 54 degrees) to half an ounce of oil of vitriol	170
23.	Water boils under the mean state of the atmosphere	212
24.	Spirit of nitre boils	242
25.	Polished brass takes a gold colour	340
26.	Brass takes a copper colour	415
27.	Foil of tin and bismuth melts	450
28.	Tin melts	490
29.	Brass takes a blue colour	500
30.	Oil of vitriol boils	546
31.	Polished iron takes a straw colour	605
32.	Lead melts	610
33.	Linseed-oil boils	620
34.	Iron polished takes a purple	660
35.	Iron polished takes a full blue	700
36.	Mercury boils	700
37.	Colours of iron are burned off	800
38.	Greatest heat of lead in fusion	820
39.	Iron just red-hot in the dark	1000
40.	Iron just red-hot by day-light	1120
41.	Iron with a glowing red by day-light	1600

* This, or perhaps, 1650 is the ordinary heat of live coals without blowing.

42. Iron

N°		Affirmative.
42.	Iron with an heat almost white	2080
43.	Iron with the white sparkling heat of the smith's forge	2780
44.	Iron in fusion is 3000 and upwards.	

To this scale I must subjoin a few remarks on some particular articles. The experiments on the freezing of mercury at Petersburgh were made with thermometers graduated after the manner of De Lisle; in whose scale, which proceeds by *descent* from heat to cold, the point of boiling water is marked 0, and the freezing point for water is 150 degrees below it. The same interval is expressed in Fahrenheit's scale by 212 — 32 = 180: whence the number of degrees in any interval, taken on Fahrenheit's scale, are to the degrees of the same interval on the scale of De Lisle, as 180 to 150, or 18 to 15, or 6 to 5. The Russian professor observed the mercury to be frozen at 470 of De Lisle: therefore, as 5 to 6 so is 470 to 564, which is the number of degrees in Fahrenheit; from which if we take his whole scale of 212 degrees, we shall have the freezing point for mercury at 352 below 0. I have set down 350 as a rounder number, and more agreeable to some parts of the account. When this

this experiment was made, the natural cold at Petersburgh was at 205 of De Lisle, that is at 34 below 0 of Fahrenheit*. Spirit of nitre repeatedly mixed with snow, by transferring the coldness of one mixture as a step to begin with in the next, under this very cold state of the atmosphere, was found to produce more than 300 degrees of artificial cold. I have set down the effect of spirit of nitre once mixed with snow; from which trial I had no encouragement to expect any success like that at Petersburgh, and therefore I did not trouble myself to proceed. The natural cold of the air was then at the freezing point. What might have been done in the frost of this last winter, 1776, when the thermometer was found as low as 0, I cannot say.

In the experiments on boiling water in vacuo, the heater, fig. 3. was employed, and a light vessel of tin, including a thermometer, was placed upon it. The ebullition began to appear at 90 degrees; and as the boiling increased, the thermometer rose to 105, where it stood when the agitation of the water

* Muschenbroek, in his philosophy, sets down —390° of Fahrenheit as the freezing point for mercury, but I cannot see on what authority.

water was most violent. During this circumstance the air was admitted; with which, the heat was raised almost instantly 15 degrees higher. At another trial, some water, already heated to 130 degrees, was placed on the heater, and this being covered with a receiver, the air was exhausted, with which the water boiled vehemently, but during the act of boiling, the heat subsided to 100, and at another trial to 94; but on the admission of the air, the heat presently rose again to 130, and upwards.

It is manifest, from these experiments, as from many others, how greatly the action of fire depends on the re-action or pressure of the incumbent air. When the air is withdrawn, the fire, naturally ascending, flows through the liquor in the vessel, as air would through a tube open at both ends. But if the farther end of such a tube were closed, and the current of air supposed to continue, it must be condensed or accumulated within the cavity of the tube. Hence it may be collected, that the sun would heat the earth but very inconsiderably, if it were not for the incumbent pressure of the air on its surface; that, therefore, it must be impossible to calculate what the heat will be in bodies placed

placed at different distances from the solar fire, unless we could also tell how far air acts upon them at the same time.

Some parts of the foregoing scale may be examined by comparing the articles with one another. The heat of lead beginning to melt is placed at 610. This was found by placing a mercurial thermometer of a particular kind in linseed oil, and suspending a thin plate of lead in the oil till it began to drop away in fusion. The greatest heat of melted lead is at 820, in which interval all the different colours assumed by polished iron are nearly comprehended; whence it will follow, that a piece of polished iron, dipped into melted lead, may be tinged with every colour, as the lead is kept in a greater or a lesser heat. If the heat be raised as high as it can be, and the iron but half immersed, the part under the surface will be dull and black, while the other parts contiguous to the surface will receive the different colours in their proper order. If the heat of lead is required for casting figures, &c. it may be adjusted to a sufficient exactness in this cheap and easy way, only by observing the colour of a polished iron dipped into it. This example may suggest others, which

will be of use to mechanics, whose success, on so many occasions, depends on the application of a proper degree of heat to the matter they are working upon.

By the method above described of mercurial immersion, the boiling heat of mercury itself came out 703, and the immersed iron had a strong blue, which did not burn off by remaining for some time in the mercury during its greatest ebullition; so it may be concluded, that it never far exceeded the heat of 700. Hence it appears, that a mercurial thermometer, if the orifice of the tube is left open to the air, may be made to shew 700 degrees of heat: by a thermometer of this sort I was able to correct some parts of the scale; and perhaps it might be applied with advantage to some others. In the higher heats it will be very well if the experiments agree within 20 or 30 degrees.

In Vol. V. part 1. of the Philosophical Transactions abridged, there is a scale of heat with no name to it; but the same is published in Mr. Cotes's Pneumatical Lectures (p. 213) as the scale of Sir Isaac Newton. In the lower articles it agrees very well with the scale obtained by other methods; but when we go higher in the scale,

the difference is considerable. If the reader desires to compare the articles of that scale with what is here offered, he may reduce any of them to our present form, by multiplying the parts of the first column into 5,233, and adding 32 to the product, which will give the corresponding degrees of Fahrenheit very nearly. Some of the numbers are as follow: human heat 95; blood heat 106½; boiling water 210; melted wax 158; melting tin 408; melting lead 540; live coals 1,034; greatest heat of live coals without blowing 1,128. These heats were collected, some of them from a thermometer of linseed oil, and others from the gradual cooling of a red-hot iron in equal intervals of time. The principle on which that celebrated philosopher proceeded is very ingenious, and may be very true in theory; but, perhaps, in practice it is too precarious to be relied upon; which will frequently be the case when we trust to the bare evidence of calculation, without some such cross examination as lesser philosophers are very willing to take advantage of.

In the experiment by which the white sparkling heat of iron was found, it was very remarkable, that when the iron had been plunged with so great an heat into the cold mercury,

mercury, it contracted a thin but hard and durable coat of filver. Iron being the only metal to which mercury will not adhere, it has been the custom to suppose some repulsion or natural antipathy between their parts; but these appearances are all over-ruled by the different degrees of heat and cold. In the hands of some practical chemist or mechanic, this fact of the consolidation of quicksilver might possibly lead to some new and useful application of that wonderful fluid. The method of consolidating it seems to depend upon communicating to it the highest possible heat, and at the same time preventing its evaporation.

The heat of iron in fusion is set down by conjecture, because its heat was not discoverable by the method of immersion; though I think it might be found in this way by retrocession, that is, by first observing the heat communicated by some melted iron, and then working afterwards for the proportion of the heat communicated by the same mass when solid, or by another of the same weight. There would be some difficulty in this; but I should be glad to see the result of it, because it is very probable I have much underrated this article, if we consider the rapidity

with which the degrees of fire increase from the iron that is just red-hot by day-light, up to the white sparkling heat of the forge.

If the heat of fire increases in a certain proportion according to the quantity of the fuel, as it is very reasonable to suppose, perhaps the scale might be extended by some observations on the fire of a glass-house furnace; and this might lead us on to some better conception of the transcendent heat of such an immense mass as the body of the sun. That fire does actually so increase, is pretty evident from the vitrifying power of a burning hay-stack, which could proceed only from the quantity of the fire. It was observed by M. Buffon, that when a large superficies was heated by his reflecting mirrors, the firing was much quicker than when only a small portion was heated, though the rays fell with equal force upon any given part of the surface *.

The fire of a large furnace for plate-glass is literally as white as snow: when a pot of their metal happens to break in the fire, the men, in order to save what they can of it, are clothed with old hats, as being of the least inflammable materials, and have ladles in

* See Phil. Trans. N°. 489, p. 504.

in their hands, with handles of eight feet in length: they only pass by and dip for the metal as quick as they can, yet in the passage they are set on fire, and their fellows stand near with water to quench them. What is here said of the colour of a glass-house fire, reminds me of a circumstance observed by a friend of mine, who had been much in the West Indies, that in the hot countries the appearance of the sun is perfectly white, and not of that yellow or reddish hue as in these northern climates.

On the Heat of Climates.

It being generally observed that the seasons in any particular climate depend upon the situation of the sun in the ecliptic; it is thence vulgarly inferred, that the heat of all climates must agree with their position in respect to the sun; and that as the greatest heat, which is as the sine of 90 degrees, will be found where the sun is perpendicular at the equator, the heat at any distance from the equator will be as the cosine of the latitude, from which it would necessarily follow, that at the pole, where the cosine vanishes, the heat (supposing the sun to be always in

the equator) will be none at all. This rule is so far from prevailing universally in all climates, that it does not take place in the same climate; for the sun has the same meridional altitude at both equinoxes, yet the autumnal season seldom fails to be warmer than the vernal. In this inquiry, therefore, we must leave all theories, and have recourse to the experience of those who can give us the proper information. The reports of all travellers and voyagers will be found to agree in this, that heat and cold depend much more on other circumstances, than on the latitude, of which the evidences are so numerous, that they will extend to almost every part of the globe. But before we launch out to examine the state of things in other climates, it will be proper to consider the ordinary courses of heat and cold in our own country, with which we are best acquainted, and by which we shall judge of others.

The common changes of the seasons in England are comprehended within 60 degrees of Fahrenheit's thermometer, from 16 to 76: in which interval, the mean degree of heat for the winter quarter is 31; the mean degree for the vernal equinox 43; for the autumnal 48; for the summer quarter 61. I set

set down these, as they were found from a series of my own observations. The noon-day heat, of what we call the summer air, is at 76; but the extraordinary heat of the summer air goes to 80, and upwards; I have seen it at 86; and, therefore, I have set this down in the scale as the hottest air of England; though there is an account in the Philosophical Transactions, that it has been observed at 88½ *. An hard frost in England is set down at 16; but I have myself seen the thermometer at 7°: and Thomas Hooker, esq. of Tunbridge, assured me, that in the late severe frost of 1776, at four o'clock one morning, he saw his own thermometer but half a degree above the cypher †. The subterranean temperature of the earth at moderate depths, in this latitude, is about 48 throughout the whole year. When the thermometer in the open air was at 85, another in my cellar (at Pluckley in Kent) the floor of which is about 10 feet below the surface of the earth, and goes into the rock with an arch

* I am informed that in this present summer, June 1780, it has been seen so high as 90 in the neighbourhood of London.

† In the Gentleman's Magazine for March 1776, a diary is inserted from Chatham, where the thermometer is marked at 3½ degrees below the cypher at Jan. 31.

arch of stone, was at 55; and in the late severe weather it was never below 36; but the mean betwixt these two is probably not the true one, because the extraordinary cold which sunk the thermometer, continued so much longer than the extraordinary heat that raised it.

I find, upon looking into my papers, that the temperature which I observed in the subterranean waters of the great cave in the Peak of Derbyshire was 48. The mean of all the middle heats above set down for the four seasons, is 46; whether the temper of the earth's body is quite so low as this, does not appear. At different depths the heat is various, and sometimes is found very high at very great depths *. These things being premised, we shall now be better able to judge of what we hear concerning the temperature of other climates.

In surveying the different parts of the world, we shall meet with a cool, or at least a moderate air, where we should expect the most violent heats; and shall likewise find great heats in the high northern latitudes, where we should expect a series of cold weather through the whole course of the year.

At

* See Nollet, tom. iv. p. 68.

At the island of Jamaica, which is within the limits of the torrid zone, the heat is not nearly so disagreeable as in the south of Spain, Gibraltar, and Minorca: and at the north side of the island of Jamaica, when the wind blows off the continent, the air is cold, and a white frost is often seen upon the ground, but never any ice. Within twelve leagues of Carthagena, which is very near the line, the mountains are covered with snow. A regiment which had been abroad at Carthagena and Jamaica, was afterwards ordered into the Highlands of Scotland: and on one day in particular, as they were on their march in the Highlands, it was agreed by the officers and all the men, that they had never felt the heat so intolerable in the West Indies. Perhaps it ought to be considered, in accounting for this, that the heat is often very great in vallies, when it is much more moderate on the hills or level grounds, on account of the reflexion of the sun's rays, especially where there are rocks and cliffs of a light colour. But the extraordinary heat in our northern latitudes is chiefly to be accounted for from the long continuance of the sun above the horizon; so that what is wanting in the direction of his rays is more

more than compensated by the duration of their influence. This is the reason why the summers are hot at Petersburgh in Russia, about 10 degrees north of London; where the corn is sown and grows up and ripens in a very short time, much sooner than in England. At Greenland, which is near 80 degrees north, the summer heat is excessive; insomuch that an experienced person, who was much versed in those parts, concluded it must be very great at the pole itself, on account of the long continuance of the sun above the horizon. In the Isle of Cherry, which is 75 degrees, the men who fish for the sea-calves are said to have felt so great an heat about mid-summer that the pitch melted and ran along the sides of their vessel. Many other extraordinary instances are to be met with, for which I cannot well account, unless we suppose that the sunshine, beside the duration of it, has some particular advantage in acting upon the denser air of the polar regions. On the other hand, the cold at Philadelphia in Pennsylvania, which place is 10 degrees nearer the sun than London, was observed to be 11 degrees below the cypher; and as the observation was not made in a sharp winter, it is supposed that the

the cold may sometimes fall to more than 20 degrees below the cypher*. The heat of the summer at the same place arose to 96 or 97; which gives above 100 degrees for the annual range of the thermometer. At Barbadoes the thermometer never rises above 86: yet at Valdagnio, within 60 miles of Venice, a learned observer assured me he saw the thermometer rise to 96 for ten days successively.

Muschenbroek informs us, that in July 1750, the heat at Leyden in Holland was 90: that the greatest heat of Senegal in Africa is from 104 to 110 degrees: and that in a voyage to Peru under the line, the thermometer was observed at 45 degrees.

All travellers who have frequented the European side of the Mediterranean sea, such as Gibraltar, Minorca, Venice, Sicily, &c. complain most of the hot wind that blows in those places, particularly in the night; the sensation of which is attended with a debility of the limbs, and a failing of the animal spirits, both of which are past expression. They give this wind the name of the *siroco*, because it comes to them from the south-east, and is supposed to arise from the lands of Africa

* Peter Kalm's Travels to North America, vol. i. p. 295.

Africa in the neighbourhood of Syria. If the heat of this was such as has been reported by a late curious traveller from England, and which from him I have set down in the scale at 112*, it is probably the hottest air that has yet been observed with any accuracy in the known world. Yet if this wind brings with it so many degrees of heat to Sicily, what must it be in Africa, its own native region? Surely it is reasonable to think that something considerable must be lost in the passage, and that the heat of such a wind at the source of it must be above what Muschenbroek sets down for the heat of Senegal. I have heard it observed by gentlemen who have been stationed at Senegal and Goree in Africa, that the climate there is subject to a burning easterly wind on certain occasions, which scorches the face like a blast from the mouth of a furnace, and if not avoided, either by lying down or repairing to some shelter, occasions present death. It is pity but they who are capable of making observations, and have the opportunity, were furnished with proper instruments for ascertaining the temperature of places, by some better rule than that fallacious one of the bodily sensations; that

* Mr. Brydone.

that we might know how much of these effects is to be ascribed to the heat: for there is undoubtedly somewhat that affects us in particular winds beside the absolute heat or cold of them; which matter will come under consideration in another place.

The heats in general seem to be higher in the East than in the West Indies. At Bengal the thermometer in June 1765, was seldom below 98, and sometimes at 104 or upwards: which however is not higher than it has been observed in Georgia, where it stands at 98 for many days together, and even in the night falls no lower than 89: twice within less than a month it was at 102; but this was in an extraordinary hot summer *. A curious gentleman having applied a thermometer to his body while he breathed in an air of 105 degrees, found it sink several degrees, and that the heat of the body in health would never raise it above 97. There is something very wonderful in the nature of animal heat: for while inanimate unorganised matter, whether fluid or solid, will soon conceive the same temper with the medium that surrounds it, the temperature of animal life, whatever it may be in different animals, continues

* Phil. Trans. vol. l. N° 102.

continues nearly the same in every medium: and vegetable life is found in some measure to partake of the same property. At the baths of Abano, a small town in the Venetian state, there is a multitude of mineral springs, strongly impregnated with sulphur, and of a boiling heat. In the midst of these boiling springs, within 3 feet of four or five of them, there is a tepid one about blood-warm, which is used for drinking. In these waters, not only the common potamogeitous and confervas, or pond weeds and water mosses, are found growing in an healthy state, but numbers of small black water beetles are likewise seen swimming about, which die on being taken out and plunged suddenly into cold water. Whether these insects are local, and formed by nature to live in this great heat, or whether by custom they are so reconciled to it as to preserve their own natural temperature, my account does not distinguish: but as the plants are of the common sorts, there seems no reason to suppose that the animals are of a peculiar formation, *sui generis*, and adapted to the nature of the place. This singular fact, which I had from an honourable person who himself observed it, hath lately been illustrated by the experience of

of some learned members of our Royal Society, who found that they were able to subsist, for a considerable time, without any great inconvenience, in an air heated far above the degree of boiling water; which heated their buckles so that they could not be touched without scorching the fingers. The philosophers of the French Academy found, long ago, by experiment, that the human body can bear the air of an oven for five minutes heated to 325°, that is 113 degrees above the heat of boiling water. Daily practice might soon reconcile the body to bear this much longer and with less offence. Water being a denser medium, affects us with its heat more than air; but such is the power of habit, that I have seen my own cook-maid take the meat from a pot of boiling water, with her bare hands, without being scalded.

These observations on the heat and cold of different climates shall be concluded with a discourse on the same subject by the ingenious and philosophical writer of Anson's Voyage; who, on occasion of the very different heats then observed in the same latitude, on the East and West sides of the coast of South America, was drawn into the fol-

 lowing

lowing digression; which I shall here subjoin in his own words:

"The ancients conceived that of the five "zones into which they divided the surface "of the globe, two only were habitable; "supposing that the heat between the tro-"pics, and the cold within the polar circles, "were too intense to be supported by man-"kind. The falsehood of this reasoning has "been long evinced; but the particular "comparison of the heat and cold of these "various climates, has as yet been very imper-"fectly considered. However, enough is "known safely to determine this position, "that all places between the tropics are far "from being the hottest on the globe, as "many of those within the polar circles are "far from enduring that extreme degree of "cold to which their situation should seem "to subject them: that is to say, that the "temperature of a place depends much more "upon other circumstances, than upon its "distance from the pole, or its proximity to "the equinoctial.

"This proposition relates to the general "temperature of places taking the whole "year round: and, in this sense, it cannot be "denied

"denied that the city of London, for instance, enjoys much warmer seasons than "the bottom of Hudson's Bay, which is "nearly in the same latitude with it; but "where the severity of the winter is so great "that it will scarcely permit the hardiest of "our garden plants to live. And if the "comparison be made between the coast of "Brazil and the western shore of South-"America; as for example, betwixt Bahia "and Lima, the difference will be still more "considerable: for although the coast of "Brazil is extremely sultry, yet the coast of "the South Seas, in the same latitude, is perhaps as temperate and tolerable as any part "of the globe; since, in ranging along it, we "did not once meet with so warm weather "as is frequent on a summer's day in England: which was still the more remarkable, as there never fell any rains to refresh and cool the air.

"The causes of this temperature in the "South Seas are not difficult to be assigned. "I am now only solicitous to establish the "truth of this assertion, that the latitude of "a place alone is no rule whereby to judge "of the degree of heat and cold which obtains there. Perhaps this position might

"be more briefly confirmed by observing, "that, on the top of the Andes, though under the equinoctial, the snow never melts "the whole year round: a criterion of cold "stronger than what is known to take place "in many parts far removed within the polar "circle.

"I have hitherto considered the temperature of the air all the year through, and "the gross estimate of heat and cold which "every one makes from his own sensation. "If this matter be examined by means of "thermometers, which in respect to the absolute degree of heat and cold are doubtless the most unerring evidences: if this "be done, the result will be indeed most "wonderful; since it will hence appear, that "the heat, in very high latitudes, as at Petersburgh, for instance, is at particular "times much greater than any that has hitherto been observed between the tropics; "and that even at London, in the year 1746, "there was the part of one day considerably "hotter than what was at any time felt by "a ship of Mr. Anson's squadron, in running from hence to Cape Horn, and back "again, and passing twice under the sun: "for, in the summer of that year, the thermometer

" mometer in London (being one of those
" graduated according to the method of
" Fahrenheit) stood once at 78°; and the
" greatest height at which a thermometer of
" the same kind stood in the foregoing ship,
" I find to be 76°; this was at St. Catha-
" rine's, in the latter end of December,
" when the sun was within about three de-
" grees of the vortex: and as to Peters-
" burgh, I find by the acts of the academy
" established there, that in the year 1734,
" on the 20th and 25th of July, the thermo-
" meter rose to 98° in the shade; that is, it
" was twenty-two divisions higher than it
" was found to be at St. Catharine's, which
" is a degree of heat that, were it not autho-
" rised by the regularity and circumspection
" with which the observations seem to have
" been made, would appear altogether in-
" credible.

" If it should be asked, how it comes to
" pass, then, that the heat, in many places
" between the tropics, is esteemed so violent
" and insufferable, when it appears by these
" instances that it is sometimes rivalled or
" exceeded in very high latitudes not far
" from the polar circle? I should answer,
" that the estimation of heat, in any particu-

" lar place, ought not to be founded upon
" that degree of heat which may now and
" then obtain there; but is rather to be de-
" duced from the medium observed in a
" whole season, or perhaps in a whole year;
" and in this light it will easily appear, how
" much more intense the same degree of
" heat may prove, by being long continued
" without remarkable variation. For in-
" stance, in comparing together St. Catha-
" rine's and Petersburgh, we will suppose the
" summer heat at St. Catharine's to be 76°,
" and the winter heat to be twenty divisions
" short of it: I do not make use of this last
" conjecture upon sufficient observation, but
" I am apt to suspect that the allowance is
" full large. Upon this supposition, then,
" the mean heat all the year round will be
" 66°, and this perhaps by night as well as
" day, with no great variation. Now those
" who have attended to thermometers will
" readily own, that a continuation of this
" degree of heat, for a length of time, would,
" by the generality of mankind, be styled
" violent and suffocating. But at Peters-
" burgh, though a few times in the year, the
" heat by a thermometer may be consider-
" ably greater than at St. Catharine's; yet

" as

" as at other times the cold is immensely " sharper; the medium for a year, or even " for one season only, would be far short of " 66°. For I find that the *(range of the)* " thermometer at Petersburgh is at least five " times greater, from its highest to its lowest " point, than what I have supposed to take " place at St. Catharine's.

" Besides this estimation of the heat of a " place, by taking the medium for a consi- " derable time together, there is another " circumstance which will still augment the " apparent heat of the warmer climates, and " diminish that of the colder, though I do " not remember to have seen it remarked in " any author. To explain myself more dis- " tinctly upon this head, I must observe, that " the measure of absolute heat, marked by " the thermometer, is not the certain crite- " rion of the sensation of heat with which " human bodies are affected; for as the pre- " sence and perpetual succession of fresh air " is necessary to our respiration, so there is " a species of tainted or stagnated air often " produced by the continuance of great " heats, which being less proper for respira- " tion, never fails to excite in us an idea of " sultriness and suffocating warmth, much

" beyond what the heat of air alone, suppos-
" ing it pure and agitated, would occasion.
" Hence it follows, that the mere inspection
" of the thermometer will never determine
" the heat which the human body feels from
" this cause: and hence it follows, too, that
" the heat, in most places between the tro-
" pics, must be more troublesome and uneasy
" than the same degree of absolute heat in a
" high latitude; for the equability and du-
" ration of the tropical heat contribute to
" impregnate the air with a multitude of
" steams and vapours from the soil and wa-
" ter, and these being many of them of an
" impure and noxious kind, and being not
" easily removed, by reason of the regularity
" of the winds in those parts, which only
" shift the exhalations from place to place,
" without dispersing them, the atmosphere
" is by this means rendered less capable of
" supporting the animal functions, and man-
" kind are consequently affected with what
" they style an intense and stifling heat:
" whereas in the higher latitudes these va-
" pours are probably raised in smaller quan-
" tities, and the irregularity and violence of
" the winds frequently disperse them; so
" that the air being in general pure and less

" stagnant, the same degree of absolute heat " is not attended with that uneasy and suf- " focating sensation. This may suffice in " general with respect to the present specu- " lation: but I cannot help wishing, as it is " a subject in which mankind, especially " travellers of all sorts, are very much in- " terested, that it were thoroughly and ac- " curately examined, and that all ships " bound to the warmer climates would fur- " nish themselves with thermometers of a " known fabric, and would observe them " daily, and register their observations: for, " considering the turn to philosophical in- " quiries, which has obtained in Europe for " the last fourscore years, it is incredible " how very rarely any thing of this kind " hath been attended to*."

Such were the speculations of this ingenious writer, which in the main are both true and curious. The complaint at the conclusion of them is now of less weight than formerly, many reports from philosophical people in foreign climates having been transmitted to the Royal Society: and I make no doubt but that Mr. Robins himself would have added many valuable observations of his

* See Anson's Voyage, book ii. cap. 5.

his own, if the climate of the East Indies had not so soon proved fatal to him, after his removal thither. In this subject there is one consideration which seems not to have occurred to him; which is, the essential difference between the air that lies contiguous to the sea and that which is contiguous to tracts of land. The observations from which he reasons were made on ship-board, consequently upon the sea: and it seems natural that the vast body of water in the sea, which can never acquire any great heat from the sun, because the deeper water is always shifting to the surface, should have a great effect in cooling the atmosphere, as the air, in a lower apartment, is kept to a more moderate temperature by the effect of a stone floor. The air contiguous to the sea can never be violently heated, unless in some harbour or bay where it is inclosed, or on some coast where it is affected by the land; and therefore in all the islands of the West Indies, the heats are daily reduced and qualified by the breezes which come from the water. This consideration suggests one good physical reason, why the proportion of sea is so large in the terraqueous globe; more especially why the land is contracted to such

narrow

narrow dimensions in those regions that lie within the torrid zone, which in the western hemisphere is very remarkable at the isthmus of Darien, and not much less in the eastern, when the general distribution of the land is considered.

I should far exceed the limits I have prescribed to myself, if I were here to examine the several concurring causes of the temperatures that obtain in particular climates: and besides, something of this kind will come before us upon another occasion. It may be sufficient here to observe, what a remarkable provision is made in the world, and the several parts of it, to keep up a perpetual change in the degrees of heat and cold. These two are antagonists, or, as Lord Bacon calls them, the very *hands of nature with which she chiefly worketh;* the one expanding, the other contracting bodies, so as to maintain an oscillatory motion in all their parts; and so serviceable are their changes in the natural world, that they are promoted every year, every day, every hour, and we may indeed say every moment. By means of the oblique position of the ecliptic, the earth is continually presenting a different face to the sun, and never receives his rays two days together

in

in the same direction. In the day and night the differences arising from the presence and absence of the sun are generally so very obvious that they need not be mentioned, but they are most remarkable in those climates where the sun at his setting makes the greatest angle with the horizon. In every hour of the day the heat varies with the sun's altitude, and also with the frequent interposition of clouds. Other vicissitudes of heat and cold are promoted by the winds. The south is warm, because it blows from the sun; the north is cold, as coming from the pole, surrounded with frozen seas; the west is mild, because it comes to us from that quarter where the effect of the sun's rays is longer retained from the direction of the annual motion, the earth on that side leaving a train of heat behind it as it proceeds in its orbit; the east is cold, as coming to us from the high mountains of the continent, covered with perpetual snows; and perhaps for another more general reason, because the eastern side of the earth is continually shifting by the annual motion into a fresh part of the sky, not yet affected by the rays that return from the earth's body; which is one reason why the eastern twilights are always shorter than

than the western, as astronomers have frequently observed. The changes which take place on so many different principles, from the seasons of the year, the hours of the day, the vicissitudes of light and darkness, the shifting of the winds, &c. are so various, that they must needs be intended to answer some very important ends in the creation.

On the Nature and Causes of Cold.

As darkness is supposed to be nothing but a privation of light, so cold has been supposed by some to be nothing but a privation of the matter of fire. But it cannot be proved that there is more of the matter of fire in a red-hot iron than in the same iron when cold, provided the bulk were to continue the same: all we can affirm is this, that the matter of fire is in a more refined and active state. The world always contains the same quantity of fire; but in different places and at different seasons the manner and degree of its action are changed. It is far from being clear that the matter of fire gives any heat at all till it is compressed and agitated in a particular manner. The higher we ascend above the vapours of the earth, which

which are subject to a tumultuous agitation, the less heat we perceive from the rays of the sun, though they are in themselves more pure and less interrupted. The flux of electric fire will pass through ice, and be long resident within it, without melting it; and if it be ever so much accumulated in the simple way, it will give no heat sensible on a thermometer: but when it is resisted and agitated by violent compression, it explodes and burns with the utmost violence, as in the solution of metals by the electric shock, which makes them red-hot, and disperses them abroad in a liquid shower of fire.

Cold and heat, then, are properties of the same element. And why not? the light which is not strong enough for us to read by, is of the same nature with that which dazzles the eyes at noon-day: the air is the same element, whether it explodes from a cannon, yields harmonious sounds from a musical instrument, blows in a storm, or stagnates in a calm. There are some occasions when it will rend an oak, and others when it will not waft a feather; yet the quantity of air about the earth is nearly the same at all seasons. In these several instances we express ourselves in different language,

guage, but the same thing is every where understood. And the same thing is to be understood when we express the different sensations we have from the several degrees of fire, whether it burns us, or heats us, or warms us, or gives us a sense of coldness only because it is below the temperature of an animal body: all these expressions relate to the various modifications and effects of one and the same medium. It is the common property of weapons to be sharp; but if they are blunt and harmless, the matter of steel which produces the effect is the same as before. When the medium of fire is descending in its temperature, we generally call it cold; and when it is ascending, we call it heat. And though, when we bring these things together, they seem to run us upon the absurdity of cold fire, yet this is an absurdity in language, not in nature.

As all heat arises from the expansive motion of fire, all cold must be owing to a cessation or diminution of that motion; so that if there could be any such thing as absolute rest in fire, there would be absolute cold. We argue that fire expands other things in virtue of its own expansion: therefore, by parity of reason, we must infer that when bodies

bodies are contracted with cold, the fire which extended them is itself contracted and quiescent. If we suppose heat and cold to be properties which infer two different substances, we ought so to distinguish them as to fix upon some point where the one ends, and the other begins; but no such point can be found or imagined. When water, with a boiling heat, is exposed to the open air, the fire of the atmosphere soon brings it down to its own present temperature. If the thermometer at the same time is reduced by art down to the cypher, it will, when left to itself, soon be raised again to the degree of the atmosphere; so that the same medium in these two instances gives heat and coldness, and therefore ought itself to be both hot and cold: but as it cannot be both, it is in reality neither, the heat and cold which we ascribe to it being no more than relative terms; or, in other words, heat and coldness are the names we give to the different impressions we receive from elementary fire.

There are many chemical experiments which are attended with the production of an artificial cold. By the mixture of some solids and fluids together, or the mixture of some fluids with others, two opposite effects are

are produced. Lime mixed with water gives a very sensible heat to it, and fumes arise which are hot and penetrating. Oil of vitriol, mixed with water, has the same effect upon it, and the like is observed in many other instances. But when sea-salt is mixed with water, the contrary happens, and the water becomes many degrees colder than before, insomuch that when sea-salt is mixed with snow, and they are stirred well together, a thermometer placed in the mixture will sink even down to the cypher, or below it, as it appears by the scale; and a vessel of water, surrounded with this mixture, will be frozen even by the fire-side. Sal ammoniac applied in the same manner will produce a more intense coldness than common salt. When either of these salts have been intimately mixed with snow, or powdered ice, a very remarkable fermentation ensues, and bubbles of an aerial appearance are generated and discharged in vast quantities at the surface, so that the mixture will seem even to froth and foam. Fermentations are so called, because when heterogeneous ingredients work together, heat is commonly produced: but we cannot speak of cold fermentations without an abuse of words; we may therefore call

call them cold ebullitions. In order to account for them, it should first be considered what happens in hot fermentations, of which these are the reverse. On such occasions we hold, that the fire which was attached in a quiescent state to any body, is decomposed and brought into action by means of some third ingredient, which either disturbs the fire, or sets it at liberty from the body which retained it. When air has access to phosphorus, the fire, which before was cold and quiescent, becomes active and burning, and, as fast as it is decomposed, goes off in fumes, and carries the volatile parts of the phosphorus along with it, which is known by a strong urinous smell, which attends the solution. In cold ebullitions the contrary happens: the fire, by the admixture of some third matter, is checked and made less active than before, or discharged by what is newly introduced. In some cases it seems as if the salt, which occasions this effect, yielded in its dissolution a different sort of ether more gross and aerial, displacing the natural fire of the water or acid with which it is mixed, and planting this other ether in its stead, which produces a temporary coldness; for it can be only temporary, because the fire of the

the atmosphere brings all things by degrees to its own temper. This account is favoured by some experiments, where one thermometer will sink in the mixture, while another will rise in the fumes that are discharged from it. For the production of cold, Monsieur Homberg, the celebrated French chemist, made the following experiment before the Royal Society:—he took a pound of corrosive sublimate, and a pound of sal ammoniac, powdering each of them apart; then he mixed both the powders very exactly, put the mixture into a phial, pouring upon it a pint and a half of distilled vinegar, and shaking the whole well together, with which the composition became so cold, that the vessel which contained it could hardly be held in the hand in the summer time; and it chanced, as he was making this mixture, that the subject froze *.

There is another way of producing a transient cold, which agrees with the old doctrine of Antiperistasis among the Aristotelians. If a vessel of water, including a thermometer, is placed in the centre of another larger vessel containing water of the same temper, and live coals are thrown suddenly

* Trans. Abr. vol. v. p. 7. Mr. Motte.

denly into the water of the larger vessel, the thermometer of the inner vessel will sink considerably, as if the expansion of the ordinary medium within the pores of that water were checked by the effect of that greater which surrounds it, and enters upon it forcibly in a contrary direction. This effect, however, lasts but a very short time, till the heat newly introduced takes place up to the common centre of the vessels. It was anciently imagined, that a surrounding heat repels and concentrates cold, and that cold, under like circumstances, has the same effect upon heat. Some modern observations have been adduced to confirm this notion, particularly from what happens in the icy cavern of Szelicze, near Mount Carpathus, which freezes in summer, and begins to melt as the winter approaches *. This phænomenon is illustrated by a practice said to be common among the Hungarians, who, when they travel through desarts, where there is neither ice nor spring water to cool their liquors, dig a pit of two feet deep, and bury their bottles of wine in it, covering them over again very close. Then they burn straw or reeds over the place; and when the fire is out,

* Trans. Abr. vol. viii. p. 664.

out, they dig up their wine as cool as if it had been put into the coldest water. It falls in my way to report many things more than I have leisure to try, and some which are absolutely out of my reach; but we suppose that philosophers in general have proceeded with such circumspection in later times, as seldom to affirm what they do not know, or at least believe, to be well authenticated. The influence of an extreme cold climate on the magnetic needle, is related by a navigator*, who observed it when his vessel was amidst the ice in Hudson's Bay, where the property of the needle was so far lost or destroyed, that the card would not traverse as usual, though the ship was in a considerable motion. The like was observed again in another season; and it was found that the needle recovered its proper motion, after it had been kept for some time near the fire. This could not happen from an unusual friction on account of the freezing of oil at the centre, because they never used any. Indeed I have no doubt but that the cold was the true cause of this phænomenon, many accounts having concurred to assure us, that

 magnetism

* Captain Christ. Middleton. See Phil. Trans. Abr. vol. viii. p. 741.

magnetism is subject to unexpected varieties and interruptions. Heat is well known to have the effect of discharging magnetism from steel; and it is by no means unreasonable, that cold should suspend it, by constringing the pores of the metal.

The principal of all the cold ebullitions is the act of freezing. When water is congealed into ice, a great number of bubbles are produced in it, and imprisoned in the body of the ice, where they are distinguishable to the sight by reason of the transparency of the substance; and when the ice melts, all these bubbles are discharged at the surface. As these bubbles are produced in the act of freezing, the water is extended in bulk about one-tenth part, and with such a force as no vessels are able to resist. It is on this account that ice is specifically lighter than water, and floats with one-tenth part of its thickness extant above the water that bears it. We may hence infer the amazing thickness of ice in the Northern Seas, when the part extant above the surface is higher than the masts of the tallest vessels. When a tract of ice is spread over the ground very strong and massy, and other ice continues to be formed underneath it, where there is

not

not room for its extension, as in the Glacieres of Switzerland, the ice that is underneath expands with such force as to crack and rend the superior strata with violent explosions, which explosions are frequently heard in the frosty climates of the polar regions, and are sometimes as loud as a cannon.

The expansive force of ice is not only of eminent use in nature, as we shall see elsewhere, but is applied on several occasions to save the labour of man, and perform such things as are beyond the reach of art. Blocks of slate-stone, which are formed in thin plates or strata, not separable by a tool, are taken out of the quarry, and exposed to the rain, which soaking into the pores of the stone, is there frozen into ice; and the ice, by its extension, separates the stone in those places where it breaks most easily, shivering it into plates of an equable thickness throughout, and proper for many different uses, but especially for covering the roofs of buildings. In the iron works, when they want to break the large old bomb-shells, in order to cast them over again, they fill them with water, and fasten up the vent, then expose them to the frost, which bursts them to pieces without farther trouble. If it is expected that

any liquor will freeze, and we wish to save the vessel, room should always be left for this accidental extension.

It has been imagined that the bubbles in frozen water are bubbles of air; but it is impossible that air, within such narrow dimensions, should exert such a force, unless we should suppose it to be incredibly condensed, which it is not by any means, neither has the fluid which is so collected the properties of air; for when it is discharged by the melting of ice in vacuo, it has no effect upon the gage of an air-pump. And besides, water purged as well as possible of its air, by being first boiled, and then placed for many hours in vacuo, will yet freeze with the same collection of bubbles, and with the same force; therefore it is not air, but the matter of fire itself, or that ether which is continually circulating through all things, which is thus collected and arrested in its passage through the water, when it is consolidated into ice.

I thought this force a proper object of inquiry, and made some experiments upon it, which are described in my Essay on the Principles of Natural Philosophy *. Since that

I have

* See p. 152, 269.

I have applied the same machine, which shews the expanding force of heat, to shew this power of frost; and it may be examined very commodiously by the same instrument, only with the addition of a brass box and cover, as in fig. 5 and 6 of plate II. which represent the box that contains the water to be frozen, with another lever, to be substituted for L, which is made broad at the end, to support a vessel with a freezing mixture, including the box of water with its bar, to be exposed to the same pressure as the bar A.

Though the force with which fire expands itself must in reason be less as its heat is diminished, yet its power in the rarefaction of ice is still too great to be completely measured by this instrument, or perhaps by any other of the kind, though I think the subject worth pursuing. From the foregoing observations this one reflexion is obvious, and will be more so when we come to the experiments of electricity, that light and fire may have powerful effects in nature, where they give no sensible heat, because it appears that they have other powers beside that of agitating bodies with heat; and, therefore, the light of the moon and stars may be working such effects as we little understand

derstand or think of, although no heat is discoverable in their rays.

Miscellaneous Observations and Experiments.

That I may not be too tedious by drawing out to a greater length a subject which is absolutely inexhaustible, I shall now only throw together a few observations and experiments, which it might be improper to omit.

1. The fire, which, in the act of boiling, overcomes the pressure of the atmosphere, will not prevail so as to effect the same thing in a second included vessel; by which it is meant, that if one smaller vessel of water be placed in a larger vessel of water, the water will never acquire a boiling heat in the interior vessel, though it boils vehemently in the exterior. It enters with its full force through the bottom of that vessel which is immediately exposed to it, but having once come into contact with the water, it is so far checked and reduced, that it cannot exert the force necessary to make water boil in a second vessel. This agrees with what we have already learned from many other experiments, that fire is an actual fluid, resisted

in its motions according to the plainest mechanical laws like air or water.

2. But little hath as yet been observed concerning the difference of bodies with respect to the conceiving of heat; for some will certainly take heat much sooner than others, and on some the same cause will produce a greater effect. Boiling water will give more heat to cold mercury, than to an equal measure of cold water; and if water and mercury are placed over the same fire in equal vessels, the mercury will grow hot sooner than the water, as well as to a much greater degree. Air takes heat the quickest of all fluids, then mercury, then petroleum, oil of turpentine, spirit of wine, &c. Oil of olives is nearly the slowest of all, which is rather extraordinary, because it is so easily affected with cold, that a much less cold will congeal it, than is requisite to the congelation of water.

In the conception of heat from the rays of the sun, much depends on the surface of bodies; they that reflect much light imbibe heat slowly, so that the same body, when polished, is heated with more difficulty than when it is rough. But the most considerable difference

difference of all, is from the colour of the surface. It is the property of white bodies to reflect light, and of black ones to admit or absorb it; therefore black bodies are found to grow very hot, when white ones, in the same situation, are but little affected. For this reason, white clothes, whatever their substance may be, are always found cooler than black ones of the same texture; and if the wall at the back of a fruit tree is painted partly white and partly black, the fruit on the black part will be forwarder than the other. Dense bodies have also the advantage of rare ones: lead painted black will take more heat from the sun, than wood of the same colour; therefore, when the density of the matter and the colour of the surface both conspire together, the reception of heat is the greatest of all. The difference occasioned by the colours of surfaces is greater than would be expected. I exposed the ball of a mercurial thermometer to the sun, and found that the heat received from the sun exceeded that of the shaded air by 27 degrees; then I painted the ball of the same thermometer with a thick coat of Indian ink, sprinkling it over while it was wet with soot,

and

and having exposed it, I found that it received 20 degrees more *.

3. Having said thus much on the reception and retention of fire in bodies, under the form of heat, it may not be amiss to add, that fire is also retained in many bodies under the form of light, of which some very unexpected instances have been discovered by experiment. There is a curious paper on this subject in the Philosophical Transactions, extracted by the ingenious Dr. Watson, from a Latin treatise published at Bolognia, by Beccarius. It is the new doctrine of this learned person, that fire adheres to bodies in the form of light, as well as in that of heat; that it is actually permanent and visible within them; and that the particles of light thus adhering, are the causes of odours. A very weak light can be visible to the eye only in very great darkness. When the sun is in the meridian, the moon and stars are totally obscured; and yet when that superior light is withdrawn, how plainly the moon and stars

* I have just now tried this, May 20, 1776. The shaded air at a north window was 61°; the sunshine upon the glass ball, with the white mercury, 88; the same on the ball made black with Indian ink and soot, 108. I wish this were tried upon all the colours.

stars appear to us. Art will produce a degree of darkness far exceeding that of the night from the absence of the sun, and in such darkness the weakest light that can be will become visible. Therefore, to judge of the illumination retained by various bodies, when brought from the fire or the sunshine, our philosopher inclosed himself in a box somewhat like a sedan chair, but made so close as to be absolutely dark within, yet with a convenience for delivering or receiving any matters he wanted to examine, without admitting any light to interrupt his observations. To take off all the impressions of former vision, he remained in this situation for half an hour, till the pupil of his eye was opened to its greatest dimensions, and thereby in readiness for a critical inspection of the smallest degrees of illumination. A piece of writing paper exposed to the heat of a naked fire, by being laid upon an iron grate, (or gridiron,) yet not so near as to scorch it, was handed in to him, and when he examined it, he found it luminous, and withal so distinguished into lights and shades, that he could discern the marks of the grate, where the bars had intercepted the fire. When the paper had been otherwise heated, by being applied

applied to an hot plate of brass, somewhat less than the paper itself, he could distinguish, by its being less luminous, the margin of the paper which had not been in contact with the plate. He found that many calcined substances visibly retain some of the light they receive in their calcination. Some calcined bodies are perpetually luminous: while such as are only torrefied retain their light but for a time; some for a few days, some for hours, and others only for a few minutes. A body, as tutty for instance, with one side rough and the other polished, was luminous on the rough side, and not on the polished; the same was observed in polished marble: whence it appears that bodies retain light most where they reflect it least; which agrees with what we observed a while ago, concerning the reception of heat from the rays of the sun.

Many transparent bodies, as glass, crystal, gems, in which we should expect this faculty in a greater degree, do not appear to have it at all; and perhaps the same texture which hinders them from being electrified, renders them also incapable of permanent illumination. Of diamonds indeed some were found luminous in the dark, others not, without

without any visible reason for the difference. However, upon the whole, this retention of light is much more general than we should have imagined, and the world is stocked with a variety of occasional phosphori, from which light is insensibly evaporating, where we should never have looked for it, nor could possibly have detected it without this subtile mode of examination.

To these observations of Beccarius I cannot help adding an experiment which was shewn to me by two very ingenious electricians*. A calcined substance, nearly of kin to the lapis Bononiensis† and the calxes examined by Beccarius, retained a very distinguishable light for near a quarter of an hour after it had received upon it a very strong electric explosion. We have therefore the same phosphorous appearance in calcarious bodies

* Mr. Henley, F. R. S. and Mr. Canton.

† I have inquired after the preparation which goes by this name, and cannot meet with any account of it. In the Philosophical Transactions, N° 21, p. 375, it is observed, that "though several persons have pretended to know the art of "preparing and calcining the Bononian stone, for keeping a "while the light once imbibed; yet there hath been indeed "but one who had the true secret of performing it. This "was an ecclesiastic, who is now dead, without having "left that skill of his to any one."

bodies excited by the rays of the sun, by a culinary fire, and by the matter of the electric explosion.

4. In the experiments relating to the scale of heat, as above described, fire appears to diffuse the prismatic colours over an heated bar of metal: on which account, those experiments belong to the science of optics, which is not now before us. I shall however observe, by the way, that those prismatic colours proceed from the sulphur or phlogiston of the metal, which the fire expels to the surface, where it settles in the form of an exceeding thin coat or plate; and this plate reflects such a particular order of rays as are suitable to its degree of thinness. It will be more or less thin, in proportion to the subtilty of the matter expelled; and as the finer parts will always be expelled first, we shall have the colours of red and yellow with the lesser heats, and blue with the greater. An ingenious writer (Edward Hussey Delaval, esq.) who, with much learning and philosophical penetration, has of late prosecuted those experiments of Sir Isaac Newton, which shew that colours are exhibited by very thin plates of pellucid media, has discovered, that all metals, when perfectly dissolved, commu-

 nicate

nicate the prismatic colours to glass in the exact order of their densities:

Gold	Red.
Lead	Orange.
Silver	Yellow.
Copper	Green.
Iron	Blue.

To account for the experiments made by Beccaria, it may be considered, that as an heated iron, which is dark by day-light, appears red and fiery when carried into a dark room, having acquired but a part of that ignition which at length renders it luminous in the sunshine; so other bodies are capable of an incipient ignition, which is perceptible to the eye in artificial darkness: and it is this incipient ignition which brings them under the denomination of phosphori. It is remarkable that a degree of light is discernible in heated oil, when viewed in such a dark medium: and that even cold water does not immediately extinguish the light imbibed by sugar, gum, paper, glue, &c. Mr. Wilson, F. R. S. who has bestowed much labour on experiments of this kind, observed a very extraordinary example of illumination in oyster-shells calcined for an hour or two in a naked coal fire; which, when the outer

dirty

dirty coat was scaled off, shewed all the prismatic colours, more vivid and glorious, as the author relates, than those of the rainbow itself. For many other curious particulars, I must refer the reader to the two treatises of Mr. Delaval and Mr. Wilson.

5. In this miscellaneous collection I should introduce the phænomenon of the Lachrymæ Batavicæ or glass drops, as being of good use to illustrate the doctrine of fire; but having spoken of them particularly in another work*, I have the less to say in this place. Mons. Le Cat, of the Academy of Paris, considered these bodies with great attention, and has many curious observations in his paper upon the subject†. If the reader will be pleased to compare his solution with mine, he will find that we differ in the direction of the matter which occasions the explosion: he supposing it to come out of the glass, and I supposing it (as I humbly think for better reasons) to enter into it. Indeed I cannot possibly see why there should be any explosion at all upon his prin-

 ciple:

* See an Essay on the First Principles of Natural Philosophy, p. 157.

† Phil. Trans. Abr. vol. x. p. 560.

ciple: the fire was in an expansive state, and wanted more room, when the drop was red-hot in a liquid state: but as soon as it was cold and solid, the contrary must have happened; so that the medium, instead of having too little room, has too much for the state it is in; and the great difficulty with which the surface is parted in breaking, far beyond what happens in other glass of the same magnitude, is a proof that there is a violent pressure upon the surface from a medium which is ready to enter as soon as the way is opened; whereas, if the effect proceeded from a medium which makes an effort from within, it would assist in the fracture, and make this glass break more easily than any other of the same size.

6. As fire is more moveable in its nature than any other matter, any extraordinary motion once excited in it, or impressed upon it, will continue for a long time. The rays of light which impinge upon a polished surface, will go off according to the angle of their incidence with the same velocity to another surface, and thence to another, insomuch that if a thousand mirrors were properly placed, the image of the sun would be received and communicated from the first to the

the last in a moment of time, provided the materials of the specula were so perfect as to permit none of the rays to be dissipated and lost in their passage. When bodies are agitated with heat, the vibratory motion continues very long, and is at last reduced, on this principle, that the adjacent element which surrounds it mixes with it, as the fire of the excited body in its turn also mixes with that, till both are brought to a state of equality: for it is the general effort of nature, in all its parts, to bring things to an equilibrium; and sometimes it is very long before this happens. In bodies of a small bulk and porous substance it is soon effected; but where the substance is close and heavy, and the bulk very great, the heat which is once excited is long retained, because it lies deep, and is therefore less exposed to the circumambient medium; on which account it is manifestly ordained in the animal frame, that the principle of vital motion is placed in the centre of the body; and the arteries, which take the lead in the circulation, are every where removed to a distance from the surface.

Many experiments might be made to determine in what proportion bodies part with their heat according to their several magni-

tudes. It has been shewn, that they part with it more slowly than they receive it; and with respect to their weight and their figure, those bodies will retain their heat the longest, which if projected through the air would retain their motion longest: and these are such as have most weight under the least surface. If a sphere of iron as large as the globe of this earth were well ignited, it would certainly be very many years in cooling; for even the lava of Vesuvius, after it has been exposed for half a year to the air, will immediately convert into vapour the rain that falls upon it*. But then we must take this into the account, that much will always depend on the nature of the surrounding medium; because bodies part with their heat much faster in vacuo than in the air, which serves to suppress and retain that fire which would otherwise evaporate. In the pure spaces of the heavens, supposing there is no superficial pressure

* A mass of lava two hundred feet deep and a hundred feet broad, which was discharged in the eruption of 1767, was examined by Sir William Hamilton in April 1771, who thrust sticks into some crevices of this lava, where they immediately took fire. On Mount Ætna it was also observed that the lava of 1766 smoked in many parts in 1769. See Observations on Vesuvius, Ætna, &c. p. 86.

pressure there, or at least very little compared with what we find upon the surface of the earth, the greatest imaginable heat will transpire in a much shorter time than it would here upon earth. Sir Isaac Newton delivers it as a rule in the cooling of all bodies, that if the times of their cooling are taken in an arithmetical progression, the heats will decrease in a geometrical one; on which principle he constructed a scale of heat, from observations taken with the greatest possible accuracy. But to go on with the mobility of fire: in electric experiments, when the fire is once excited to an unusual motion in an electrised glass, it will continue flashing of itself at intervals for a considerable time. The like happens when the parts of a sonorous body are put into a tremor; the symptoms of which continue long if the body is large and the stroke forcible. The sound is conveyed to the senses by the air; but the medium which agitates the parts of the sounding body is the same that agitates bodies with heat, though the vibratory motion of sound is of a different quality from that of heat. From these several instances, which are perfectly distinguished from each other in their kind, it is

obvious, that when motion is observed to continue in any bodies whatsoever, that motion is no more than the consequence of another motion that has taken place in the element of fire, which alone has perfect mobility.

7. If we attempt to compute the heat of bodies placed at different distances from the sun in the heavens, we are at a loss for data to proceed upon, because the case is very complicated, and depends upon the concurrence of many circumstances. When the surface of the earth is very hot in the summer with the sun's rays, this depends on several circumstances, but chiefly on the density of the air which re-acts upon the light. When we ascend to a lighter air at a distance from the surface, the heat of the earth, even under the equinoctial, is not sufficient to melt the snow that lies upon it. At the perpendicular height of one mile, it is generally found that the snow continues through the whole year; and if it were known in what ratio the heat decreases as we recede from the earth, it would be easy to compute at what height in the atmosphere mercury would be frozen. Where the re-action is wanting from a superficial pressure, but

little

little effect can be expected from the rays of the sun. This leads us directly to another speculation; that as it appears from the observations we make on the instantaneous occultation of the fixt stars by the moon, that this planet has no atmosphere, it is not probable that her orb conceives any heat from her illumination, but rather that an intense coldness prevails in it, such as the condition of this earth can give us no conception of; a coldness farther below the cypher of Fahrenheit, than the fire of a glass-house is above it. What influence the rays of the moon on this consideration may have in tempering and modifying the fire of the earth's atmosphere, may be a matter worthy of some meditation.

8. The effects of the solar rays, when collected to a focus by mirrors and glasses of very great power, are too curious to be passed over in silence. Two noble instruments of different kinds were made for this purpose, the one a concave metallic mirror by the Villettes, of Lyons, in France, three feet seven inches in diameter; the other a dioptric burning-glass, nearly of the same size, by Tschirnhaus. It is only by means of these instruments that we are made acquainted

quainted with the utmost effects of fire. The area of Villette's mirror is said to be upwards of 7000 times as great as the focus; so that if all the parallel rays that fall on the speculum were collected perfectly into the focus, and the increase of the heat is supposed to be as the density of the rays, the heat of the focus must then be 7000 times as great as the heat of the parallel rays. But many abatements are here to be made; first, on account of the imperfection of the figure of the mirror, which is part of a sphere, whereby many of the rays do not coincide with the right focus; secondly, of the metal, by the pores of which many rays are absorbed; thirdly, on account of the minute asperities in the polishing, which occasion a multitude of irregular reflexions; fourthly, the interruption, whatever it may be, which the reflected rays meet with, by interfering with the direct rays in the same space; and lastly, which is the greatest consideration of all, the coldness of the surrounding medium in which a fire of so small dimensions is supported. If on all these accounts we take only the half of 7000, and suppose that the sun's rays add only 30 degrees of heat to the temperature of the atmosphere, we shall then

have above an hundred thousand degrees of heat in the focus, which is upwards of thirty times as much heat as we find in melted iron, taking it at something more than 3000 degrees above the cold of Iceland. If this calculation, or any thing like to it, does really take place in Villette's mirror, it is not to be wondered at that such surprising effects are produced by it. Monsieur Buffon, with his plane specula, which increased the heat of the sun but 140 times, if so much, could melt silver at a great distance; but then he had a very considerable advantage from the magnitude of his focus, a larger quantity of fire having certainly more power than a smaller for very obvious reasons, particularly because the centre of it is better guarded, and consequently less interrupted by the penetration of the surrounding atmospherical cold.

The dioptric glass of Tschirnhaus being the most convenient that ever was applied to the purpose of burning, and nearly of the same power with the great concave speculum above mentioned, I shall recite the principal effects of that, as they are delivered in the Memoirs of the Royal Academy for the year 1699.

1. Every

1. Every sort of wood, whether hard or green, or soaked in water, catches fire in a moment.

2. Iron, in thin plates, grows red in a moment, and melts.

3. Tiles, slates, and all manner of earths grow red in a moment, and vitrify.

4. Sulphur, pitch, and all resinous bodies melt under water.

5. Fir wood exposed to the focus under water, seems not to be changed; but when broken, its inside is found burnt to a coal.

6. If a cavity is made in a coal of hard wood, and the substance to be acted upon are put into it, the effect is infinitely more violent; [because the quantity of fire is thereby increased, and the exposed body is guarded from the cold of the atmosphere.]

7. Any metal whatsoever thus inclosed in the cavity of a piece of charcoal, melts in a moment, and the fire sparkles as in a forge. Some metals, kept thus in fusion, fly quite away.

8. The ashes of wood, herbs, paper, linen, and all vegetable substances, turn to a transparent glass in a moment.

9. The bodies most difficult to be wrought upon,

upon, are white substances, which remain white in melting, such as flint, English chalk, lime, &c.

10. All metals vitrify on a China plate, provided the plate itself is so thick as not to melt, and the fire is communicated by degrees.

11. When a little copper is melted in this manner, and thrown quickly into cold water, it produces so violent a shock, that the strongest earthen vessels break, and the copper is dissipated, so that not the least grain of it can be found *.

12. Some bodies, when first vitrified, are as transparent as crystal; but when cold, become white as milk, and opake: while others, which are opake in fusion, become finely transparent when cold.

13. Bodies which change into a transparent glass, become much more beautiful if they are continued for some time in the focus.

14. The

* When they cast plates of copper at a foundery, they are obliged to ufe fuch precaution, that when the moulds, betwixt which the plates are to be cast, have been well dried and heated, they wrap them round with blankets to prevent the access of any moisture; the smallest vapour of which would not only dissipate the metal to atoms, but blow up the works, and overturn even the house itself.

14. The rays of the moon, when concentrated either by this glass, or Villette's speculum, give no sensible heat, though the light is so vivid as to dazzle the eyes.

15. It was observed of the metallic mirror, that it always burns most intensely in cold weather, and becomes weak when the weather is violently hot. It is also much weakened when the rays pass to the focus through the fumes of charcoal. The reason seems to be the same in both cases, the solar rays being disturbed in their direction by the agitations of elementary fire; on which some observations have been made in a former part of this discourse.

The Philological Consideration of Fire.

After the preceding experimental inquiry into the nature of fire, it may not be amiss to step beyond the limits of natural philosophy, into the philological history of fire, both profane and sacred.. The learned reader may here find some amusement; but if any should think himself uninterested in this part of our subject, he may pass on, if he pleases, to the next physical discourse upon the nature of air.

An

An agent of such importance as fire toward the government of the natural world, and of such use in all the concerns of life, must needs have attracted the notice of mankind, and driven them into many speculations of different sorts. We find accordingly that the ancient Heathens, particularly the Pythagoreans, Platonists, and Stoics, not only admitted it into their philosophy, filling the universe with its substance, and deducing from it all the greatest effects in nature, but they were so struck with the powers and uses of it in the world, that they even paid divine honours to it. All the parts of nature were deified by the most ancient theology of heathenism; but of all that were advanced to this dignity, fire was the principal. Among the Romans we find it so early as the days of Numa, whose Greek and Latin volumes, which were destroyed, are reported to have contained many wonderful secrets in philosophy and divinity; and Numa himself is supposed, with good reason, to have derived his doctrines from the same fountain as Pythagoras did afterwards; but, however this might be, we are sure the Greeks had this worship of fire before

fore the days of Numa *. He built a temple of an orbicular form, to represent, as *Plutarch interprets*, the system of the heavens; which temple was the conservatory of an holy and perpetual fire, kindled at first by the reflexions of the sun beams, and placed in the centre of the building, as the astronomy of that early time placed the sun in the centre of the world; and from them the doctrine was revived of late times by Cusanus and Copernicus.

The Vesta of the Romans was no other than the element of fire; the same with the Εστια of the Greeks, which the best philologists derive from the Esh of the Hebrews, or אשתא of the Chaldeans and Phœnicians; referring also the Ηφαιστος, Hephæstus, of the Greeks, the Apis and Serapis of the Egyptians, to the same original. As fire is the purest body in nature, its worshippers supposed it ought to be honoured with the purest kind of devotion; with which view the female votaries of this deity were bound to inviolable chastity, under the penalty of being buried alive.

According to the late system of the learned Mr.

* See Plutarch, in Vit. Numæ.

Mr. Bryant, in his Mythology, the worship of fire is nearly as old as the flood, having been first propagated by the posterity of Ham, in Egypt, who called themselves Ammonians, and carried this worship of fire with them wherever they went, introducing the same ritual which they had observed in Egypt, and erecting their *puratheia*, or *fire-temples*, in all their settlements*. Plutarch confesses that the Romans, in the days of Numa, borrowed their worship of fire from the Greeks at Athens and Delphi. From the Greeks we may trace it backwards to the Ur of the Chaldeans; on which the learned Glassius remarks †, that "Ur is the name of a city "wherein the sacred fire was conserved and "worshipped by the Chaldeans, whence it "was called *Ur*, which otherwise signifies "*fire*." And for the first institution of this sacred fire among the Chaldeans, we must go back to Nimrod, of whom the Alexandrian Chronicon writes, "the Assyrians "called Nimrod, Ninus; this man taught "the Assyrians to worship fire ‡." Mr. Bry-

* See Bryant's Mythol. vol. ii. p. 2.

† Philol. Sacr. lib. iv. tract 3. obs. 6.

‡ Αυτον Νινον τον Νεβρωδ' οι Ασσυριοι προσηγορευσαν· Ουτος διδασκει Ασσυριους σεβειν το πυρ. p. 64.

ant derives this worship from the sons of Ham, Cush, and Mizraim, by the way of Egypt; but if we have it also from Nimrod and the Assyrians, by the way of Babylon, it is pretty plain that fire was the primitive, or at least the principal object of idolatrous worship, and common to all idolaters from the first apostacy at Babel.

The most learned interpreters of the Heathen Mythology, among the Heathens themselves, agree that fire is the object to be understood under the names of many of their deities: their Jupiter, though generally and more properly applied to the air, seems to have included the whole expanse of fire and air in the heavens; according to these words of Ennius, the doctrine of which, as Cicero intimates, was universally assented to,

> "Aspice hoc sublime candens, quem invocant
> "Omnes Jovem *."———

And Juno, by whom we are to understand the air, was connected with him in most of his operations. They supposed him to be that universal fire which is the life and soul of all nature, and affirmed that the human soul is nothing more than a part of the same element: from which doctrine, it is clear that

* Cic. de Nat. Deor. lib. ii. cap. 2.

that they held fire to be a living and intelligent being, which indeed is expressed without any reserve by Hippocrates, who, speaking of the influences of this element in the human body, attributes to it *mind* and *understanding** The Stoics supposed God to be an intelligent fiery substance, extended through the world, not subsisting under any form, but capable of assuming any form at pleasure; and Cicero, in the person of Balbus, a Stoic, argues, from the words of Plato, that the celestial ardor or fire of nature, which moves all things, hath its own motion from itself, and consequently must have life and understanding, without which there can be no such thing as spontaneous motion †.

* Εν τȣ́τῳ ψυχῇ, νόος, φρόνησις. Hippoc. de Diæt. If the elements were to be much studied and understood by men of a particular cast of mind, it would not be very surprising, if what hath happened so frequently in the world, should happen again at the revival of the elementary philosophy; I mean, that men should relapse into the Stoical opinion of the divinity of fire: And to confirm my suspicion, I can assure the reader I have had conversation and correspondence with an ingenious man, known to many of the literati in Europe, who pleaded seriously for the actual divinity of elementary light, and exclaimed in words to this effect—*Deus, ecce Deus!—quid quærimus ultra?*

† Quoniam ex mundi ardore motus omnis oritur, is autem ardor

By the fabulous history of Vulcan, the terrestrial and subterraneous fire is to be understood as being the fabricator of all those mineral exhalations which mount up into the sky, and furnish Jupiter with the materials for his thunder and lightning. The pure etherial fire of the heaven, says Phurnutus*, is Jupiter; that which is in common use upon earth, and which is instrumental in the works of art, is Vulcan, who is reported to have fallen from heaven, because men were imagined to have received the fire they first made use of from the stroke of lightning; and he is feigned to be lame, and walking with a stick, because culinary fire will not continue to burn without sticks, or some other like fuel, to *support it*. He was also called Mulciber, which name some have attempted to derive from the Latin; but the learned Turner contends, that it resolves itself naturally into the two words, Melech Abir, *powerful king or ruler*, the same that was worshipped by the Ammonites in the East, under the name of Moloch, in honour of

ardor non alieno impulsu, sed suâ sponte movetur, animus sit necesse est. Cic. ibid. cap. 12.

* Ο μεν γαρ αιθηρ και το διαυγες και καθαρον πυρ, Ζευς εστι. Το δε εν χρησει και αερο μιγες, Ἡφαιστος.

of whom they made their children pass through the fire, sometimes perhaps to be purified and consecrated, but generally to be sacrificed and burnt to death *.

With the Persians fire was an object of worship from the earliest times, under the names of *Amanus* and *Mithras;* and it is retained as such at this day by the Geberrs or Gaurs, a sect of Indian philosophers, who, near the city of Baku, where there is a spontaneous fire breaking out of the earth, pay their devotions before an altar, near which is a large hollow cane, from whose end a blue flame issues, in colour and gentleness not unlike the flame of a lamp that burns with

 spirits,

* Non modo traductos sed etiam crematos in idoli sacrificium pueros illos constanter affirmo. Selden. de Diis Syris Syntag. i. cap. 6. *Adrammelech*, mentioned 2 Kings xvii. 31. is another name of the same deity, ADIR MELECH, *excellent king;* and he was served with the same cruel rites as Moloch, the Sepharvites, who bordered upon Persia, being said to have burnt their children in the fire to him. He is mentioned in company with two other powers nearly allied to him, *Nergal* the revolving light, and *Ashima* the flowing fire. "We conceive" (saith Fuller in his Palestine) "this *Nergal* of the Cuthites to be a *constant fire*, which "they adored as the symbol of the sun, notoriously known "to be the grand deity of the Persians." See book iv. p. 134. See also the learned Mr. Parkhurst's Hebrew Lexicon, under the word מלך.

spirits, but seemingly more pure. They say it has continued ever since the flood, and will last to the world's end. A little way from the temple is a low clift of a rock, in which there is an horizontal gap, two feet from the ground, near six long, and about three broad, from whence a constant flame issues, of the colour and nature already described. When the wind blows, it sometimes rises eight feet high, but much lower in still weather. They do not perceive that the flame makes any impression on the rock*.

Fire hath such an affinity to light, that the same word hath sometimes comprehended them both. The *Ur* of the Chaldeans was fire; the *Horus* of the Egyptians was light: and the reason is plain; because fire and light are united at the body of the sun, and by him diffused over the world. Therefore, if we consider fire as it resides in the sun, we shall get to the root of most of the heathen mythologic divinity. So universal was the attachment to this fire, that Macrobius undertook to reduce all the names of all the deities in the known world to the one object of the sun and its attributes. He accounted

on

* These particulars are extracted from the pious and truly patriotic Mr. Hanway's Travels.

on the same principle for the religious veneration that was paid to some particular animals. When idolaters treated animals with such divine honours as seem to us utterly unaccountable, it was for the sake of some mystical alliance to the grand objects of their devotion, the solar fire and solar light. Spotted bulls, red cows, yellow lions, white rams, were consecrated, not for their own sakes, but in their emblematic capacity. The apostacy of the Israelites in the Wilderness from the true God to the golden calf, was occasioned by a prior attachment to the sacred rites of the Egyptian idolatry: and the calves that were afterwards set up in Dan and Bethel were probably derived from the same original. The votaries of fire in Persia have a particular veneration for a red cow; which would be an instance of stupidity below barbarism itself, unless it proceeded from some idolatrous accommodation of that animal to the element of fire: and in this capacity, even the onions of Egypt, notwithstanding that well-known sarcasm of Juvenal*, may be made sense of it, if their several involucra

* "Porrum aut cepe nefas violare, ac frangere morsu,
"O sanctas gentes, quibus hæc nascuntur in hortis
"Numina!"——

were considered as emblematical of the several concentric spheres in the solar system, as some learned men have very ingeniously supposed*. The accommodation of the sacred animals to the properties of the solar fire, is so learnedly commented upon by Macrobius, that I shall translate some of his words: "The Egyptians consecrated a lion "in that part of the heavens where the heat "of the sun is most powerful, because that "animal seems to derive his nature from the "sun, excelling all other creatures in fire "and force, as the sun exceeds the other "lights of heaven. His eyes likewise are "bright and fiery, as the sun with an open "and fiery aspect surveys the world. The "Lybians represented their Jupiter Hammon, which was the setting sun, with the "horns of a ram, with which that animal "exerts its strength as the sun acts by its "rays. The worship of Egypt abundantly "shews that the bull is to be referred to the "sun; which is plain from the worship of a "bull at Heliopolis, the city of the sun; and "of the bull Apis at Memphis, where it was "an emblem of the sun; and of the other "bull

* Consult the Hebrew Lexicon of Mr. Parkhurst, under the word שם.

"bull called Pacis, consecrated in the mag-"nificent temple of Apollo at Hermunthis*." The celebrated pyramids, which have excited the wonder of the world, and are so ancient that the names of their authors are buried in oblivion, seem to be no other than stupendous monuments of the first idolatry of Egypt, originally erected in honour of fire, as their name (*απο τυ πυρος*) suggests, as well as their figure, of which Ammianus Marcellinus gives this account, "quia figura "in acutum desinens ab geometris sic ap-"pellatur quod in morem ignis in conum "ingruat."

* Ægyptii animal consecravere eâ cœli parte quâ maximè anno cursu sol valido effervet calore, leonisque inibi signum domicilium solis appellant, quia id animal videtur ex naturâ solis substantiam ducere; primumque impetu et calore præstat animalia, uti præstat sol sidera—idemque oculis patentibus atque igneis cernitur semper, ut sol patenti igneoque oculo terram conspectu perpetuo atque infatigabili cernit—Ideo et Hammonem, quem Deum solem occidentem Libyes existimant, arietinis cornibus fingunt, quibus maximè id animal valet, sicut sol radiis.—Taurum vero ad solem referri multiplici ratione Ægyptius cultus ostendit: vel quia apud Heliopolim taurum soli consecratum, quem Neton cognominant, maximè colunt: vel quia bos Apis in civitate Memphi, solis instar, excipitur: vel quia in oppido Hermunthi magnifico Apollinis templo, consecratum soli colunt taurum, Pacin cognominantes. Macrob. Sat. lib. i. cap. 21.

"ingruat*." In the ancient discourse of Timæus the Locrian, the author delivers it as the doctrine of the most early philosophers, that the particles of fire are of a pyramidal form, and penetrate all other bodies in consequence of it. This notion is of such high antiquity, that the word *pyramis* was probably a recognition of it; and if it prevailed where the Pythagorean philosophy was afterwards borrowed, this will give the best reason we can find, why fire was honoured with this figure in particular. The obelisk was nearly related to the pyramid, and was erected, as Pliny informs us†, with the same religious intention: though I apprehend the obelisk was rather intended to express a ray of light, than the figure of its constituent particles.

Wheresoever fire was worshipped in the *puratheia* of antiquity after the manner of Numa, we may suppose that there *that* solar system prevailed which places the solar fire in the centre; and that this was really the universal opinion of the most ancient Heathens.

* Cæl. Rhodig. lib. xxlii. cap. 6.

† Trabes ex eo facere reges quodam certamine, obeliscos vocantes, solis numini sacratos. Plin. lib. xxxvi. cap. 8.

thens. This doctrine agrees much better with that name they gave to the sun in his physical capacity, calling him *cor cœli* the heart of heaven*; which illustration and allusion is probably of very great antiquity, because it cannot with any propriety be applied to the more modern Ptolemaic hypothesis. The analogy is very striking; for as the heart is in the centre of the animal system, so is the sun in the centre of the world: as the heart is the fountain of the blood, so is the sun the fountain of light and fire: as the heart is the life of the body, and the centre of heat and motion, so is the sun the life and heat of the world, and the first mover of the mundane system: when the heart ceases to beat, the circuit of life is at an end; and if the sun should cease to act, a total stagnation would take place throughout the whole frame of nature. Macrobius, pursuing this analogy, says, *solem autem ignis ætherei fontem dictum esse retulimus; hoc est ergo sol in æthere quod in animali cor*—"we "have before observed that the sun is called "the fountain of the etherial fire; therefore "the sun is in the heavens, what the heart "is in animals:" from which it is obvious, that

* Macrob. in Somn. Scip. lib. i. 20.

that as there cannot be a perennial fountain in nature without a return of its own waters; and the heart cannot send out its blood but in circulation, and in virtue of what it receives; this illustration is very imperfect, unless the sun itself is supposed to act on the same principle, and to be rendered a perennial fountain of fire by the continual return of its own matter. If this is admitted, the analogy is perfect and beautiful: and it is by no means unreasonable to think that it might be so taken and understood by the philosophers of antiquity who first applied it. Since the circulation of the blood has been known, this analogy has been taken up with advantage by the great Harvey himself, who first of all the moderns explained to us with sufficient accuracy this important branch of natural philosophy. He observed, that the heart of animals is the foundation of life, the chief ruler of all things in the animal system, the sun of the microcosm, from which flows all its strength and vigour*. The philosophers of antiquity called the sun the heart of the microcosm; the moderns call the heart the

* Cor animalium fundamentum est vitæ, princeps omnium, microcosmi sol, a quo vigor omnis et robur emanat. Harv. Ded. ad Libr. de Circ. Sang.

the sun of the microcosm. There must be something very striking in the analogy which is thus convertible, and has been taken up at both ends by such different persons, at such remote periods of time. The savage philosophy of America seems to have comprehended in it this relation between the animal system and the frame of nature. Acosta, in his History of the Indies, reports, that in the human sacrifices of the Mexicans, the high priest pulled out the heart with his hands, which he shewed smoking to the sun, to whom he offered this heat and fume of the heart, and presently he turned toward the idol, and cast the heart at his face*.

Before I close this philological inquiry, we are to consider the use of fire in theology, as it has been applied in the sacred writings. The common properties of fire are, its purity, its splendor, its swiftness, its heat, its force and penetrating power, by which it searches and pervades all other matter. These properties are selected to give us ideas of the most sublime objects in the intellectual world, of which no verbal description, without this assistance from nature, could give us any adequate conception.

Fire,

* Lib. v, p. 385.

Fire, for the purity and subtilty of it, expresses the nature and powers of spiritual beings, even of God himself; who is said to have made *his angels spirits, and his ministers a flame of fire:* by which it is to be understood, that the heavenly ministers of God, employed in his service, are like air or spirit, invisible; and as a flame of fire, swift, active, and powerful; able and ready to accomplish in a moment of time every office they are sent upon. It is true, in a literal sense, that the elements of air and fire are the angels or instruments of the Creator in the physical government of the world; and so plain is this philosophy, that we may call it *natural* in more senses than one, for we have it by nature: but it is also clear that these agents, in the symbolical language of the Scripture, are taken to signify intellectual beings, who *excel in strength,* and act in subordination to the divine power: nor indeed can any thing so well express the invisible messengers of God, as those instruments which are employed daily in the offices of nature.

But then again, as these elements give us all the notions we are able to form of power and perfection, they are frequently applied

to the powers and perfections of the Deity; who is described to us as having his residence amidst the glories of inaccessible light, and is said to *clothe himself with light as with a garment.* His nature not admitting either of the evil of sin or the weakness of ignorance, *God is light, and in him is no darkness at all.* He is expressly called by the name of the sun*, because there is but one sun in the heavens, as there is one true God, the maker of all things, who, like the great ruler of day, is the fountain of light and life, the light of the understanding, and the life of the soul. As a beneficent being, the author of all good, he is signified by the quickening beams of the sun: but in respect of his justice, as He is the author of vengeance, his wrath is said to be *kindled* and to *burn as fire.* Nothing is hid from the heat of fire; neither can any being resist the force of it: therefore it is made use of to express that inquisitorial power of divine justice, which can neither be resisted nor avoided, and which shall *try every man's work,* of what sort it is. The purer metals are refined by the action of fire, and cleared of their dross; but all that is base and refuse is separated

* Psalm lxxxiv. 11. The Lord God is a sun and a shield.

rated and destroyed: with allusion to which, they who are to fall under the divine displeasure are compared to *chaff*, and *stubble*, and *thorns;* and God himself, in the exercise of his justice upon them, is said to be *a consuming fire**. When a sacrifice was offered up, it was sometimes consumed by fire immediately from heaven, (which was a mark of its acceptance;) but in the ordinary way it was burnt by the common fire of the altar. The fire which fell upon the victim, should in justice have fallen upon the offerer, for whom it was accepted, and who escaped by means of this substitution: so that the institution of sacrificature was a plain intimation of this great doctrine, that no man can escape the fire of the divine justice, but through the acceptance of an appointed victim to divert that wrath, which must otherwise act upon him as a consuming fire: and the universal practice of the heathen world, though in many respects absurd and monstrous, as all their imitations were, was a wonderful recognition of this doctrine, and prepared them at length for the reception of the Christian revelation, with its one universal sacrifice.

The

* Hebrews xii. 29.

The effects of the revealed word of God, in which all his attributes are manifested, and which is the grand instrument in his dispensations toward mankind, are illustrated to us in the same way, by the effects of natural fire; the light, the swiftness, the heat, the force of fire, are all ascribed to it; it is a *lamp to the feet*, and a *light to the eyes;* it *runneth swiftly*, even as the rays of the sun are propagated to the extremity of the heavens, which was verified by the rapidity of its progress through the world, at the preaching of the gospel: it kindles the flames of zeal and devotion, and charity in the affections; which effect of it is described in those words of the two disciples, who, on a great occasion, were instructed out of it by their master, *Did not our hearts burn within us, while he talked with us by the way, and while he opened unto us the Scriptures?* The word of God being the great rule of our actions, it operates upon the conscience in such a manner as to try and open to a man's own self the secrets of his heart; and it shall one day scrutinize, with irresistible force, the hearts of all men: in which capacity the *word of God is quick and powerful, and sharper than any two-edged sword, piercing even to* the

*the dividing asunder of soul and spirit, and of the joints and marrow, and is a discerner of the thoughts and intents of the heart**: in a word, its power in this respect is such as nothing but the all-penetrating power of light, and the sharpness of fire itself, can represent or explain to us.

With a view to these properties of fire, when the word was given on the day of Pentecost to the tongues of the apostles, an emblematic exhibition of it sat upon the heads of each of them in the form of a flame of fire: they were appointed to shine as lights in the world, *holding forth the word of life* in every language; and, therefore, those fiery tongues were cloven or parted, as flame generally is, by the resistance of the air, when it mounts upwards. The harmony of the elements, on occasion of this exhibition, is of physical consideration, and deserves well to be explained: for, while the fire that appeared denoted the quickening heat, the illuminating power, the rapid progress and irresistible force of the divine word; the

rushing

* Hebr. iv. 12. If the reader considers this passage attentively as it stands in the context, it will seem rather to belong to the *personal* word of God, as the judge of men, and the searcher of hearts.

rushing mighty wind, which attended the effect of inspiration, and without which there is naturally neither speech nor language in the organs of man, denoted that power of the invisible spirit, by means of which *their sound went out into all lands, and their words unto the ends of the world.*

These few observations, which might have been carried on much farther, are sufficient to answer my purpose in pointing out the philological use of fire in the science of theology. In producing them, I follow the example of our great Newton, who held it allowable in natural philosophy to discourse about God and his attributes *, and in his own practice reasoned freely from the Scripture. To him I should have needed no apology; and every other wise and good man will wish to see the relation between philosophy and divinity every day farther opened, and better established.

* Et hæc de Deo; de quo utique ex phænominis disserere, ad philosophiam experimentalem pertinet. Newt. Prin. Schol. Gener.

Nec quidquam aliud est philosophia, si interpretari velis, quam studium sapientiæ. Sapientia autem est (ut a veteribus philosophis definitum est) rerum *divinarum* & humanarum, causarumque quibus hæ continentur, scientia. Cic. de Off. lib. ii. cap. 2.

There is a curious observation in Lactantius, which belongs properly to this subject. Among other arguments to shew the superiority of man in the creation, and the immortality of his nature, he produces this; that of all the creatures known to us, man is the only one that has the use and command of the element of fire. He is familiar with that heavenly substance, without which there is neither light nor life, while the most powerful and ferocious of beasts are alarmed by it, and fly from it. He is intrusted with a power most like to that of God himself, who has the direction of all the elements; and therefore he has a privilege which distinguishes him, and sets him above all the creation, and gives him an alliance with the divine nature. How dreadful would it have been, if brute creatures had been intrusted with the same liberty! if there had been the use of fire, where there is not the use of reason!

What would Lactantius have said, if he had been witness to the present state of philosophy, when we have obtained the art of using and directing the force of fire, independent of its heat, as the great cause of motion in the world?—of even drawing it down from the clouds of heaven, and di-

verting

verting (as we seem to do) the stroke of lightning itself? Instead of being puffed up with pride and insolence, let us regard this rather as a gift of Providence, than a discovery of human wit: let us, in the words of the Scripture, *glorify God, who* (for some wise and good end) *hath given such power unto men:* and let us make a wise and devout use of it.

The most ancient heathen philosophers, when they contemplated this wonderful privilege of man, in enjoying the use and dominion of the element of fire, that παντεχνυ πυρος σελας*, like to God himself, persuaded themselves that as it was a privilege too great for man's estate in the world, it was originally stolen from heaven; and that this very theft was the crime which brought all manner of evil into the world. I have frequently wondered at this doctrine, which is plainly taken from the Mosaic history, where the original crime consisted in a desire of being

 equal

* Παντεχνυ πυρος σελας—*the brightness of fire, the universal artificer:* this expression is very strong and beautiful, and is taken from the Prometheus of Eschylus, the plot of which is founded entirely on this supposed theft of fire, the crime that made the propitiatory sufferings of Prometheus necessary.

equal to God: the heathens interpreted that desire to consist in aspiring to the familiar use of fire, and stealing it from heaven for that purpose. They could not see how we are so much *like gods* in any other respect.

DIS-

DISCOURSE V.

On Air, Sound, Music, &c.

AIR may properly be called a *fluid*, because its parts move freely among themselves, so that it flows like other liquids, and follows the general laws of hydrostatics; but it has some peculiar properties which distinguish it from other fluids, particularly its compressibility and elasticity.

The air is hard to be understood by an experimental analysis, on account of the subtilty of its parts, and the heterogeneous matter which is mixed with it. In the air of the atmosphere, which we commonly breathe, we have a compound, which contains diffused in it a subtile vapour from the waters of the earth and clouds, and with this, all such parts from earthy substances as are volatile; as the parts of sulphurs, volatile oils, volatile salts, and even earths, minerals, and metals, when greatly refined and subtilized.

The various parts which enter into this

compound fluid of the atmosphere, have perplexed the subject to such a degree, with those who have undertaken to study the nature of the air, that some have supposed air to be nothing but water rarefied, others nothing but salt of some kind in another form. Thus we might dispute about wine, beer, and spirits, till we had lost sight of the element of water; but here we are in less danger, because water is a grosser fluid, and more obvious in its simple form. When all other parts are removed which enter into the composition of the atmosphere, there certainly remains a fluid, which is the vehicle and substratum of them all; insomuch, that if there were neither earth, nor salt, nor oil, nor sulphur, nor water, still there would be that air which gives motion to the lungs, and is the spring of animal life. This simple fluid is the first object of inquiry to those who consider the nature of the air; and the properties of air, which arise from the mixture of other things with it, are to be regarded rather as accidents than properties.

But when we have done all we can to reduce air to its native simplicity, still it is a compound; for the air in which we move, and

and by which we live, is a mixture of air and fire. All the elementary part of it, which is not air, is fire; and where there is perfect fire, there is no air. If a glass vessel is hermetically sealed in the middle of a furnace, and its neck be afterwards inverted in water, and broken off, the space will be nearly filled with water, after the manner as when a common vacuum has been made by exsuction. Air is therefore something, which, though it be constantly flowing into a fire, cannot subsist there as air, but is by some means reduced to a fluid, which, when cold, approaches to the nature of a vacuum *. Many arguments occur to us, as well from the course of nature itself, as from experiment, (some of the most remarkable of which will come in their order toward the latter end of this discourse,) which, when taken all together and compared, are sufficient to prove that the etherial element which surrounds us, and is now generally acknowledged to be a mixture of air and fire, is but one thing in kind, but consisting of parts differing in degrees

* This experiment cannot be made but in a fire where glass will not melt, therefore it cannot be made completely; and some air, though extremely rare and little, will still be found, as Boerhaave teaches us.

degrees of subtilty, from the grossest air to the most refined fire; with a gradation so insensible, that we shall never be able to say where air ends, and fire begins; as the light of the rainbow grows so dilute by degrees, that no line can be drawn between its edge and the uncoloured sky. Yet, from the grossest air to the most intense fire, the progression is so remote, that philosophers have connected air and fire by the mediation of what they call a *subtile matter*, partaking of the nature of both, being neither so gross as to be excluded by the surfaces of solid bodies, nor yet endued with all the subtilty of fire, at least not with the force of burning fire. The Abbé Nollet calls that fluid which enters into the receiver through the glass at every stroke of an air-pump, to supply the place of the air that goes out, *un matiere subtile de la nature de l'air* *: as if he had supposed both to be one thing in nature, but differing in degree of subtilty.

A very obvious phænomenon may be proposed, which, when more attentively considered, presents us in a sensible manner with a sort of middle term between the two extremes of air and fire; I mean the coloured spectrum

* Vol. iv. p. 447.

spectrum of the prism. That there is a gradation in the force of the light when separated by the prism, is evident to the eye, if it considers the whole together in the coloured spectrum, and much more when it receives the homogeneous rays of the several orders singly; for the eye is dazzled with the brightness of the red rays, but is able to bear the radiance of the blue without the least inconvenience. I have a method of detaching the colours for this particular experiment, which is too long to be described here. There is likewise a mechanical argument to demonstrate that the different rays have different powers; for the rays which pass through any medium with the greater power, will be less turned out of their course; and as the rays least refrangible are the red ones, reason agrees with sense in giving them the greatest force. Now light is the mediating substance between fire and air, and its properties shew us this alliance. Its two extremes are red and blue; the former is the colour of fire, the latter of air. The first appearance of fire is with redness; and the body of air which we look through in the sky, is blue. The spectrum, therefore, of the coloured light shews us its alliance to fire in one extreme,

and

and its alliance to air in the other. The red rays either are fire, or would be such under certain circumstances; while the shades of blue vanish into air, or would seem to do so, if we could pursue them far enough; but when they cease to be coloured, they cease to be visible. Besides, we cannot suppose that any particles will pass the pores of the glass, so gross as to deserve the name of air: I only mean to say, that this extreme is allied to the air, as the other is allied to fire. The yellow rays, between the two extremes, may perhaps not improperly be taken for the genuine colour of the solar light, as distinguished from fire and air; philosophers have, therefore, made gold the symbol of the solar light, on account of its yellow colour and its splendour.

That air and fire are different conditions of the same elementary matter of the heavens, is so far from being new, that it is a doctrine of great antiquity particularly insisted upon by Timæus the Locrian, and embraced by the Pythagoreans and Platonists. The Cartesians saw that such a thing was necessary to account for many effects in nature, and therefore accommodated to this purpose their materia primi, and materia secundi elementi.

But

But all this was hypothetical; if we follow nature and reality, we must find either two sorts of air, or two sorts of fire: in other words, we must make air and fire homogeneous; and it is by no means unnatural that they should be the same in kind, though different in condition, because the like is observable in other instances; and what is common and familiar in one case, can be neither incredible nor absurd in a similar case. If air resolves itself into fire, and fire in its turn, by some certain association of its parts, reverts to air, there is nothing more in this than what we commonly observe in the element of water. It assumes the solidity of ice; it coalesces into the fleecy form of snow; it becomes rare and impalpable in vapour; and yet, under all these conditions, it is nothing but the one simple substance of water, to which it returns sooner or later as it happens to be acted npon. When we affirm that a snow-ball and the smoke of a caldron are of the same substance, who can deny it? Yet a child, who should feel both, would not readily understand how that could be.

It is more easily seen how two different conditions of fluidity and solidity obtain in

olive oil: it becomes fluid with warmth, and the more it is heated, the more perfectly it is dissolved; but when the cold acts upon it, we see it concrete into little masses, and become granulated; which masses, when united farther to each other, constitute a solid. When solid, it is no longer transparent; but when perfectly fluid as it can be, it becomes bright like the light itself, and resembles it also in its colour *. The same accident happens to the blood, which is a fluid consisting of a serous liquid, with dissoluble masses of a red colour floating in it; and they who have studied the texture of it with a microscope, have discovered that each of these are transmuted occasionally into the other. These parts are intimately mixed, and work together for the purposes of animal life, so long as the blood flows warm within the vessels of the body; but when exposed to the air, and stagnant, they are separated—the red massules concrete into a crassamentum, and the serum, draining away from them, becomes an insipid lymphatic fluid, which, in appearance, partakes but little of the nature of blood.

* The reader will see hereafter, that heated oil is actually so retentive of the matter of fire, as to appear luminous in the dark.

blood. A mutable condition in the fluid of air, the vital fluid of the macrocosm, has nothing more singular in it than these mutations which are known to take place in the vital fluid of the animal system. If the natural constitution of the air is agreeable to this analogy, we must understand the matter of the heavens as one vast fluid, the parts of which differ in magnitude, so that some will be stopped by the surfaces of bodies, while others more subtile pass freely through their pores; thus some will be acting without bodies, others within them; some will heat bodies, others will cool them; some will enter into bodies of a looser texture, and be excluded by others of a closer; some will compress, others will divide: and thus the two great and universal effects of consolidation and dissolution, or generation and corruption, will be carried on in the world.

This doctrine of a sameness of substance in the finer and grosser parts of the atmosphere, or of air and fire, as we now speak, was espoused early by an eminent member of the Royal Society at its first establishment, who had the honour of being its first president, the Lord Viscount Brounker: he supposed "the purer part of the air to be of

"the like nature with the grosser part; and "though finer than the rest, so as to pene- "trate glass, which the grosser will not "(there being in all sorts of grains some "greater than others, and which will not, "pass so fine a sieve,) yet of a springy na- "ture as the grosser parts are *." From this constitution in the air so many things follow, that it would be impossible to explain or even to recount them all. It gives us a distinction, which is the hinge whereupon most of the operations of nature turn. But its first and greatest use in our present subject, is to explain that well-known property of the air, which is called its elasticity; the force with which it resists compression, and restores itself to its first dimensions, or even exceeds them, which is not the case with any other fluid.

Of the Elasticity of the Air.

I say nothing here of the several hypotheses invented to explain the elasticity of the air, having considered them particularly, so far as my purpose required, upon another occa-

* See Phil. Trans. Abr. vol. ii. p. 27.

occasion*. It will now be generally allowed, that air, in a larger sense, is a mixture of air and fire, and that these two cannot be divided without some violence; which violence will be resisted, as it is the constant effort of nature, by an universal *stress*, to which all bodies are exposed, to keep air and fire duly intermixt, as circumstances require: and in consequence of this resistance, the air is elastic; or rather, its elasticity is the very act of such resistance. When air is compressed into a smaller volume, some of its fire, which no surface can confine, is forced out of it. This fire, by the aforesaid general effort of nature, endeavours to re-enter, and reduce the compressed air to the same density with the other air that surrounds it. Thus the compressed air will seem to expand itself by some property of its own, when it is actually expanded by fire. Hence it will follow, that a single particle of air, considered in itself, can have no elasticity: fire must intervene, and act among a number of its parts, before this effect can take place. In this I say nothing but what has been said before by many learned men; amongst

* See the Essay on the First Principles of Natural Philosophy, book ii. chap. 5.

amongst the rest by Mr. Amontons, a celebrated French philosopher, who maintained that air is elastic "only in virtue of the "fiery particles it contains; and that it is "impossible absolutely to drive out all the "fire, and consequently to make a perfect "condensation*." The same must follow from the doctrine above proposed by the Lord Brounker.

Many fallacious experiments upon air, as air only, have been made and described, without any regard to the fire which co-operates with it. Thus it has been demonstrated, that a small particle of air is extended till it occupies a space above an hundred millions of times larger than at first; and this in the vacuum of an air-pump, where the air by computation, perhaps, is not rarefied one hundred times. It should be considered how the air is apparently enlarged by the accession of fire, contributing to occupy that space, which is supposed to be filled by an extension of simple air. The air in such cases is really extended somewhat after the manner in which fluids are *diluted*. One ounce of ink, mixed with an hogshead of

* See Shaw's Boerhaave. edit. 2. vol. i. p. 293, in the note (*b*).

of pure water, may be extended through the whole, and we may say it is rarefied to that dimension; and as the particles in such a case cannot possibly touch one another as they did before, we may imagine there is some repellency in them: but though they do not touch one another, they touch something else, and are sustained upon statical principles. This we suppose (allowing for the difference between the nature of the two fluids) to be the case with the air; which is no otherwise extended than as it is made more dilute by the mixture of a greater proportion of fire in any given space.

As it does not appear that there is a single experiment to evince any elasticity in air independent of fire, we may therefore deduce from the power of fire all the laws of its elasticity, in the following order:

1. All air is expanded by fire in a certain degree; and this holds universally, because the lowest degree of fire, or that point at which fire ceases to be active, has never yet been discovered, nor can be; for when mercury is frozen with a degree of cold three hundred degrees below the point of freezing, air is still elastic as before. When there is no obstruction in the way to limit the ex-

 pansion,

pansion, it is the effort of fire to expand air *in infinitum;* for, fire acts as if every point of space which it occupies were a point of radiance. Its centre is every where, and its circumference no where. We have seen above, that air, though greatly expanded by fire, cannot be totally expelled from any space including it, by any degree of heat whatsoever. In a mean state of the air, the heat of boiling water expands it about one-third; as is found by inverting an empty phial (perfectly dry within) in boiling water, and letting it remain there till the air and water are cool, when it will be filled about one-third with water; which shews that so much of the air was expelled by the heat, and consequently that the expansion of the air was in that proportion. By the addition of a small quantity of water to wet the inside of the phial, the fire will totally expel the air, and make such a perfect vacuum, that when all is cool the phial shall be filled entirely with water. The vapour of boiling water is expanded with such force, and unites itself in such a manner to the included air, that both are carried off together, and the space so evacuated is justly thought to be a better vacuum than the Torricellian: it

it is, strictly speaking, a vacuum of a vacuum; because nothing remains but a medium more subtile than that common fire of the atmosphere, which remains in the air-pump or Torricellian vacuum. The most simple experiment for finding with accuracy the expansions of the air under all different degrees of heat, between the point of freezing and the heat of boiling water, is that described by Mr. Hawksbee in his physico-mechanical treatise, p. 218.

2. Air is naturally in a state of compression, from the expansion of other air which lies next to it; to which we may add the weight of the incumbent air, which is more or less according to the density of the air and the altitude of the column.

3. Therefore, the same degree of heat will expand air more in proportion as the compressing force is removed. When a flaccid bladder is placed under the receiver of an air-pump, and the compressing force is withdrawn by exhausting the air from the outside of the bladder, the included air is extended, as it would be if the same bladder were exposed to the heat of a fire. For it is the same thing in effect to subtract the air from without, as to add more heat to the air

 within,

within. Therefore the heat in this case is still the true cause of the additional extension under the receiver, though there is no additional heat. There is no occasion for it: the same heat under these circumstances will have a greater effect. If all the compressing force could be withdrawn, and the space were infinite, the air would be infinitely extended. This case of the flaccid bladder explains the reason why the vacuum of an air-pump produces so many of the same effects with actual fire.

4. The resistance of air to any compressing force is as the compressing force itself, because re-action is equal and contrary to action; in other words, the fire endeavours to re-enter with a force equal to that which expels it. Hence the air is always a counterbalance to itself, and naturally in equilibrio, like other fluids. Air compressed by twice the weight of the atmosphere, is reduced to half the space: by four times that weight, to one quarter of the space; and so on, in a geometrical progression, supposing the degree of heat to be always the same. Air, at any depth under water, is compressed by the weight of the water: and as a column of water 34 feet in depth is equal in

weight

weight to the pressure of the atmosphere, the diver in his bell, when he goes to the depth of 50 fathom, breathes an air compressed by the weight of 9 atmospheres, without being destroyed.

5. The elasticity of any parcel of air which is subject to the pressure of the atmosphere, is equal to the weight of the atmosphere. This holds if the air is ever so much rarefied. Let the cistern of a barometer, with part of the lower end of the tube, be inclosed in a flaccid bladder, so as to be air-tight. When this bladder is held near a fire, and the included air is rarefied to twice or three times the first dimensions, the mercury will still remain at the same height: for the rarer air, by the additional force of the expanding fire, is a counterbalance to the air without, as it was at first. What it loses in density, it gains in elasticity; or in other words, the elasticity is increased in the same proportion as the density is diminished; and therefore the barometer is stationary under all the variations of elasticity and density. If a barometer could possibly be placed where air is thus rarefied by fire an hundred times, it would shew the elastic force of that air to be equal in effect to the

 ordinary

ordinary pressure of the atmosphere: and air so rarefied would be a counterbalance to the denser air of the atmosphere.

6. Air more condensed is rendered more elastic, by an equal degree of heat, than air which is more rarefied; and this in proportion to its density. If air with one degree of density is rendered twice as elastic by 300 degrees of heat; air with two degrees of density will become twice as elastic with 150 degrees of heat; so that the heat required to produce a given elasticity, will be reciprocally as the density. Here I wish for a series of experiments to prove the effects of different degrees of heat on air of different densities; but I cannot recollect where to find them; and I have neither leisure, nor apparatus, to make them for myself.

From this article, it may be conceived, that if air is extremely condensed at great depths in the lower parts of the earth, as it must be by its situation, the application of heat may have such prodigious effects as to produce convulsions in the body of the earth, and even a disruption of the parts, extending to the surface. How far quiescent air, when raised by fire from the bodies wherein it is lodged, may be subject to the same laws with

with condensed air, is worthy of inquiry; and the subject comprehends the rationale of the expansive force of gunpowder, of which we have spoken in another place.

By considering air as a mixture of air and fire, we may see the reason of some very obscure phænomena, which have little or no relation to its elasticity. One of these I shall mention here, and reserve others for a fitter place. A blast of cold air, continued for some time, will communicate heat to the ball of a thermometer, and raise it several degrees; as we have already seen in the Discourse on Fire. The air impelled by the blast against the surface of the glass, is stopped there; but the fire that goes with the blast enters the surface, (as the finer grains of any pulverised matter will pass through a sieve,) and produces an agitation within the pores of the included fluid. After the same manner, the air which enters the lungs in respiration may deposit some of its fire at every successive impression, and the fund of animal heat may be kept up in part on this principle*; though I apprehend several

* This idea has lately been pursued by an ingenious writer, in a pamphlet on Animal Heat, &c. which the reader

veral other circumstances must be taken in, before we can give a satisfactory account of it: but that matter is not now before us.

The elasticity of the air, as a force or spring of motion, is applied mechanically in a great variety of philosophical instruments, a particular account of which would carry me out too far, and is not within the limits of my present design. The chief of these is the air-pump; from which the air is exhausted on the principle of its own elasticity. Condensed air, by its pressure on the surface of the water contained in the same vessel with it, gives motion to the stream of an artificial fountain. With great condensation, it will give motion to leaden bullets in an air-gun, much after the manner of gunpowder, and nearly with the same force. Many other applications of the air's elasticity are described in these books of philosophy, which profess to deliver such things. The treatises which a beginner will find most useful, are Clare's Motion of Fluids, and Regnault's Philosophical Conversations, translated by Dale, vol. i.

On

reader may consult. See Crawford's Experiments and Observations on Animal Heat, and the Inflammation of Combustible Bodies.

On the Weight and Moisture of the Atmosphere.

By the word *atmosphere,* we mean that heterogeneous mixture of air, vapour, and terrestrial exhalations, which surrounds the sphere of the earth, and is extended to the regions of the sky. This fluid mass is found to gravitate, or to have weight upon the earth on which it rests; and its parts are also found to gravitate upon one another, so that the inferior are more compressed than the superior. If a glass vessel, open at the top, is covered closely with the hand, and the air is exhausted from the vessel, so that the counterbalance is taken away from below, the incumbent air is immediately perceived to press on the back of the hand with a vast weight, so as to force a considerable part of the palm into the orifice of the glass. This occasions a sensation as if it were a suction from beneath; but the whole force is actually that of a weight on the upper side. The whole surface of the body is at all times subject to this pressure, which amounts to about 14 pounds averdupois upon every square inch; but force being opposed

to

to force on all sides, we are not sensible of the effect, till the pressure is removed from some part, and the balance destroyed. Air is compressed by the weight of incumbent water, as by the weight of incumbent air; and hence the air contained in the bell used by divers is compressed into half its space when the bell is about 30 feet below the surface of the sea; at the depth of 60 feet, or 10 fathoms, it is compressed by thrice the weight of the atmosphere; at 100 feet it is reduced to less than one quarter of its natural space: and the effect of air so compressed is very hurtful to the blood-vessels and the auditory membrane, so as to endanger life on some occasions. This shews us that the natural weight of the air at the earth's surface is duly tempered, with consideration of the welfare of man's body; which would suffer in some respects, if the weight of the air were much greater or less than it now is. The wisdom of making this provision is ascribed to the Creator, in the book of Job, chap. xxviii. 24, 25: *He looketh to the ends of the earth, and seeth under the whole heaven; to make the weight for the winds, and he weigheth the waters by measure.*

It was known very anciently, that leathern bottles,

bottles, when inflated with air, weighed more upon a balance than when they were empty and flaccid. The like experiment may now be tried very cheaply on a blown bladder, which will be found sensibly heavier than when the air is expelled. In a proper vessel of copper we can weigh air of different densities, and compare them together; or we can exhaust the air, and weigh a vacuum, at least by comparison. By many statical experiments, which have been made with the greatest circumspection, it is found that the weight of air, under a mean state of the atmosphere, is to the weight of water as 1 to 850. But the weight of air is very different at different times; and this difference proceeds from two causes. When air is more rarefied by heat, it is lighter; when it has more moisture, it is heavier. There is a difficulty in this part of the subject, which I could never clear up to my own satisfaction. All other matter, but that which is the cause of gravity, must gravitate; therefore the grosser air must gravitate. Yet the gravity of those matters which are incorporated with the air, interfere so much in our experiments, that it is hard to draw the line between the native and the adventitious gravity of air.

Air

Air is 850 times lighter than water; so that water 850 times rarefied in vapour will have the same gravity as air: and if air should contain water about 1000 times rarefied, then the whole weight we attribute to air will nearly be due to the water contained in it. I have found cold moist air weigh heavier than the drier air of an apartment; and this under such circumstances, that I could not but impute the difference chiefly to the moisture. It therefore seems to me so difficult to adjust the gravity of simple air, that at present I am obliged to leave it for farther examination.

That air contains much water may be shewn by many experiments. The slacking of quick lime, by exposing it to the air, shews us that water enough is applied for this purpose by the air itself. Such alkaline salts as are of a more fiery nature than lime, will shew this sooner and better. Light clouds of water may be seen to separate from the air, when it becomes rarefied about $\frac{1}{4}$ or $\frac{1}{3}$ by exhaustion in the receiver of an air-pump; and if a glass be never so clean and dry when the air is exhausted from it, the air, when re-admitted, never fails to deposit a strong dew all over its internal surface. The air which enters

enters first is instantly rarefied, and its water is separated from it, till the quantity which follows restores the equilibrium. Hence it happens, that we are obliged to wipe the inside of the glass after a few experiments, if it is required that the vessel should be pellucid. To shew this more sensibly, let a mixture of pounded ice and salt be put into any kind of vessel, and stirred about for some time. Though the air of the room be ever so pure and dry in appearance, a frozen dew will gather apace on the outside of the vessel, which, in a short time, will increase to a thick shining crust of hoar frost, with which the outside of the vessel will be invested, as high as the freezing composition reaches within side. The reason here is the same as before; fresh clouds of moisture are presented every moment to the outside of the vessel, by reason of the fire rushing into it to restore the equilibrium; and in passing it leaves the air and water behind at the surface, where fresh quantities of water are accumulated and fixed, as the freezing proceeds. The sweating of marbles and pavements in warm moist weather is to be accounted for in the same manner. During a course of cold weather, the stone pavements

and walls of a house, with other solid objects, become very cold; but when the warmer air enters the house at a change of weather, its fire penetrating cold bodies, to reduce them to the general temper, deposits its vapour at the surface in its passage. Every fluid that is warm will sustain more of any foreign matter than the same fluid when cold; therefore warm air will sustain more water than cold air. This is partly owing to the greater agitation of bodies with a greater degree of heat. Light bodies will float about in disturbed air, which settle to the earth when the air is at rest: therefore, in certain cases, nothing more is requisite than a greater degree of coldness to make the air drop its moisture. In a frosty night, when the air abroad is colder than the air within, the dampness of the internal air settles on the glass panes of the windows, and is frozen within side into beautiful forms, of which we shall speak more particularly hereafter.

The rays of light from the sun, moon, and stars, suffer a refraction in passing to a spectator upon the earth, through the medium of the atmosphere, so that every object in the heavens appears above its place; or, in other terms, its apparent altitude, by refraction, is greater

greater than its true altitude. This refraction is greatest of all at the horizon, and decreases very fast as the altitude increases; insomuch that the refraction at the horizon, differs from the refraction at one degree above the horizon, by about one-third part of the whole quantity. At the horizon, in this climate, it is found to be 33′ *. In climates nearer to the equator, where the air is purer, refraction is less; and in the colder climates, nearer to the pole, it increases exceedingly, and is a happy provision for lengthening the appearance of the light to those regions so remote from the sun. Gassendus relates, that some Hollanders, who wintered in Nova Zembla, in lat. 75°, within 15 degrees of the pole, were surprised with a sight of the sun 17 days before they expected him in the horizon. This difference was owing to the greater refraction of the atmosphere in that latitude;

* A table of refractions, calculated by Sir Isaac Newton, and given to Dr. Halley, is to be found, together with some observations upon it, in Phil. Trans. Abr. vol. vi. p. 167. This table was afterwards much improved by Dr. Bradley. I have a table of refractions in manuscript, under the name of Mr. Flamstead, which is very nearly the same with that afterwards published by Dr. Halley. Dr. Bradley's table is calculated for that state of the air when the barometer is at 29.6, and the thermometer at 50° of Fahrenheit.

latitude; and if we compute, we shall find that the difference of the sun's declination for that time amounts to more than four degrees. The sun should have appeared to them when his declination south was 15 degrees; but he appeared 17 days earlier, when his declination was 19° 42″. This is a prodigious difference, not to be accounted for from the density of the air, as measured by the barometer; we must, therefore, have recourse to the density of the frozen vapours in the sky. An atmosphere of this kind at Hudson's Bay, 16 degrees farther from the pole than Nova Zembla, is described by Captain Middleton: "The air is filled with in-"numerable particles of ice, very sharp and "angular, and plainly perceptible to the "naked eye. I have several times this win-"ter tried to make observations of some "celestial bodies, particularly the emersions "of the satellites of Jupiter, with reflecting "and refracting telescopes; but the metals "and glasses, by that time I could fix them "to the object, were covered a quarter of an "inch thick with ice*." The variations of the barometer, though greater in the more northerly parts than with us, are yet inconsiderable,

* See Phil. Trans. Abr. vol. viii. p. 470.

siderable, compared with the variations of refraction. Many observations have convinced me, that the barometer is not an index to the refraction of the air; the differences of which arise chiefly from the coldness of the air, and the density of the vapours: whence it seems reasonable that the whole refraction, whatever it may be, should rather be ascribed to aerial vapours, than to the air considered simply in itself.

During my residence at Wadenho, in Northamptonshire, about the year 1760, &c. where I was master of an observatory, which I had built, and furnished with instruments chiefly of my own constructing; I had daily opportunities of observing the refractions of the atmosphere, though I never raised any theory from my observations, nor were they sufficient for the purpose. I find, by my register, that, in the month of April 1760, when the weather was clear and frosty, the point of a spire steeple near the horizon, at the distance of eight miles, appeared higher in the morning and after sun-set by 2′ 31″, than at the noon of the same day; and thus it would continue rising and falling at different hours of the day, though the barometer was all the time invariably at the point of 30 inches.

inches. If the barometer were a true index to the density of the air, and if the refraction of the air were as its density, refraction might then be truly estimated by the barometer: but neither of these principles are true; for, as we have seen above, the barometer will be at the same height, according to circumstances, with air of different densities; and air of the same density will be differently charged with vapours, according to the state of the weather, or the influence of the sun at different hours of the day. The thermometer is a better direction in this respect than the barometer; and I would add to both, where it conveniently can be done, a telescope with a micrometer fixed to a certain distant object near the horizon. I shall dismiss the subject of refraction, after I have mentioned one remarkable case related in the Philosophical Transactions, by Dr. Nettleton: "I frequently observed," says he, "by pointing a quadrant to the tops of "some of our neighbouring mountains, that "they would appear higher in the morning "before sun-rise, and also late in the even-"ing, than at noon, in a clear day, by se-"veral minutes: particularly one morning "in December last, when the vapours lay

"con-

"condensed in the vallies, and the air above "was very pure, the top of a mountain at "some distance from hence appeared more "elevated by above 30 minutes, than it had "done in the beginning of September, about "noon, on a very clear day *."

When the air is so loaded with vapours that we view objects through a mist, they appear larger to us, as if the mist had a magnifying power. But here we are under a deception; for, because those objects are not seen so distinctly as they ought to be, we refer them in our judgment to a wrong distance, at which they would appear under a smaller angle to the eye.

The transparency of the air upon the continent, so much greater than we are accustomed to, who inhabit an island, has a surprising effect in deceiving the judgment of

 strangers,

* See Phil. Trans. Abr. vol. vi. part ii. p. 44.

The ingenious Mr. Brydone, in his Travels into Sicily, is persuaded that the height of Ætna might be accurately taken by geometrical mensuration; but I apprehend the refraction occasioned by the difference between that rare medium at the summit, and the air at the level of the sea, is at all times so considerable, and so difficult to be ascertained, that it will be an insuperable objection, and the mountain by this method will always be computed to be higher than it really is. See vol. 1. p. 225. edit. 3.

strangers, with respect to distances. Objects are never wont to be seen very distinctly with us, unless they are near at hand; but there, objects at great distances are much more clearly distinguished. When you are sitting in an air so hot as to make your clothes insupportable, you will think you are just bordering upon the regions of frost and snow, the white heads of the Alps appear so distinct and so near at hand. When you sit at Naples, and look over the bay to the island of Caprea, the objects in it are so distinct that you would suppose it to be six miles off at the farthest. A gentleman who resided there some time, and had a desire to visit the island, assured me he should have ventured to it in an open boat if he had not been better advised. This island is really at the distance of 27 miles; and there is generally a large surf, which makes it impossible to land in a small vessel; but the waves are so diminished by their distance, that the sea appears smooth and flattering to those who embark at Naples.

On the Motion of the Air in Wind, and its Velocity.

Air retains its name so long as it is quiet, or

or moves gently; but when it moves with force, it is called *wind*. This distinction, being founded in nature, occurs in other languages. In Latin, air has the name of *aura*, and *spiritus*, from *spiro*, to *blow* or *breathe*, while its motion is moderate; but if it becomes more violent, it is called *ventus*.

Naturalists have many experiments to illustrate the several principles on which wind is produced. According to the season or the place, winds are sometimes derived from one of these principles, sometimes from another, and it happens not seldom that different causes conspire together.

Fire or heat, which gives elasticity to the air, is also the principal cause of the winds, as will be considered more particularly in the Discourse upon the Weather. No fire can burn without producing two currents of air; one toward it, and another from it. In the firing of gunpowder in the open air, it is very remarkable that any light body suspended near the blast, so as to move freely, is first attracted by the fire, and then repelled, which looks as if the first impulse was from the air acting on fire before the fire can act upon that. However this may be, it is certain that air flows *toward* a fire in a dense

 state,

state, and from it in a more expanded or rarefied, when it is carried aloft with smoke and vapour. These two currents in common cases move obliquely, as if one was a continuation of the other; but it is possible for them to move in contrary directions, and even to touch one another. At the mouth of a heated oven, after all the fire has been long withdrawn, we feel a wind which enters it, and another which comes out of it. The same is with good reason supposed to happen at the torrid zone, where a denser wind comes in below, nearly at right angles to the equator, and a more rarefied one is flying off above toward the poles. Some of these things have already been considered in the Discourse upon Fire; but the two subjects are so nearly allied in many particulars, that it is scarcely possible to avoid some repetitions.

If air is rarefied by diminution, as when part of it is exhausted from a vessel; other air will endeavour to press in, and restore the equilibrium: and it is a general rule, that air which is denser flies to that which is rarer, if fire conspires with the motion: if air is condensed in any close vessel, it will rush out with violence as soon as it has liberty: and this way also a wind will be produced:

duced: and in every case, the more the equilibrium is interrupted, it will be restored with the greater force.

Another origin of wind, and that of very great consideration, is from the body of the earth. At great depths, and in cold caverns of vast rocks, which have communication with the lower parts by cracks and fissures, the air will in many places be much condensed, and will be coming forth continually, as occasion requires, to keep a balance above, and temper the changes of the atmosphere. There are likewise certain materials in the earth, and in the waters, from whence large quantities of air, first deposited and then discharged by a process of natural chemistry, are sent abroad, either by means of the sun's action from above, or subterraneous fires below, or fermentations arising from accidental mixtures, to keep up the common stock, and excite such ventilations as are necessary to the welfare of the world.

On all the above principles winds are generated; and there may be others unknown to us: for the production of wind is a subject too complicated and obscure to be understood in all its parts. The derivation of winds from the fissures and caverns of the earth,

earth, has been treated by some as fabulous; but it is a question of great importance to the true philosophy of the air; and therefore I shall resume it in another place, to which it properly belongs. There is undoubtedly a provision made for the recruiting of the atmosphere by a chemistry carried on below. All sorts of exhalations are sent up from thence to the superior air; such as hot vapours, cold blasts, watery steams, and fiery eruptions. It was said above, that the wind will blow from any space where the air is more condensed than that with which it communicates: consequently, it will blow from a space where the barometer has been found to stand higher in the cold caverns of a rocky mountain, than in the free air of the same region; whence a wind must necessarily follow from the mountain into the atmosphere; and so it was observed, that cold chilling blasts were breaking forth from the vents, or *spiracula*, as they are called, of the place.

It is agreeable to the laws of mechanics, that when the wind has greater force, it must have greater velocity, supposing its density to be the same: but we seem to have no rule established for discovering its velocity from its

its force, as we can infer the velocity of a bullet from the effect of its blow upon a proper obstacle. Custom has given different names, which afford a gross distinction between winds of different forces; as a gentle air, a brisk air, a fresh gale, a hard gale, a storm, a violent storm, a hurricane.

When there are detachments of clouds with a mixture of sunshine, the velocity of the wind may be nearly traced by the flight of their shadow along the ground: and when the wind is brisk, its course may be at the rate of 10 or 12 miles in an hour. In storms, when the heavens are dark with clouds, if the wind rages by violent gusts at intervals, which commonly is the case, a grove of trees may be seen to bend under the force, and if its course is attended to, other trees at a sufficient distance may be seen to bend under the same blast; so that the space run over in a given time may be discovered. By this rule it has been found that the wind in great storms flies at the rate of 60 miles in an hour: some say 70, or upwards. This is only $\frac{1}{13}$th part of the velocity of sound: but that depends on another affection of the same element. When the air first begins to rush into the vacuum of an air-pump, its motion has

has been calculated at 1300 feet in a second; which is beyond the velocity of sound: and hence it has been collected, that one inch difference of the barometer may be sufficient to raise a storm.

The velocity of the air which follows a cannon bullet in its flight, is so great, that the force of it is reported to have occasioned such a violent bruise as brings instant death to those who are within the sphere of its action. Niewentyt has an easy experiment to shew that such a wind always follows a projectile. If a bullet is dropt from some height into a vessel of water, the air that follows it will descend along with it into the water, and come up again in bubbles to the surface. When the hand is moved swiftly through the air with the palm foremost, a cold wind may be felt very sensibly upon the back of it. Hence it has been inferred, that a storm of hail, which consists of an infinite number of small projectiles, may be sufficient to raise a temporary wind in the air.

It is vulgarly supposed, that the wind has a straight course, and blows directly from a certain point of the compass to the point that is opposite. This is true in a larger sense; but if we observe it more accurately,

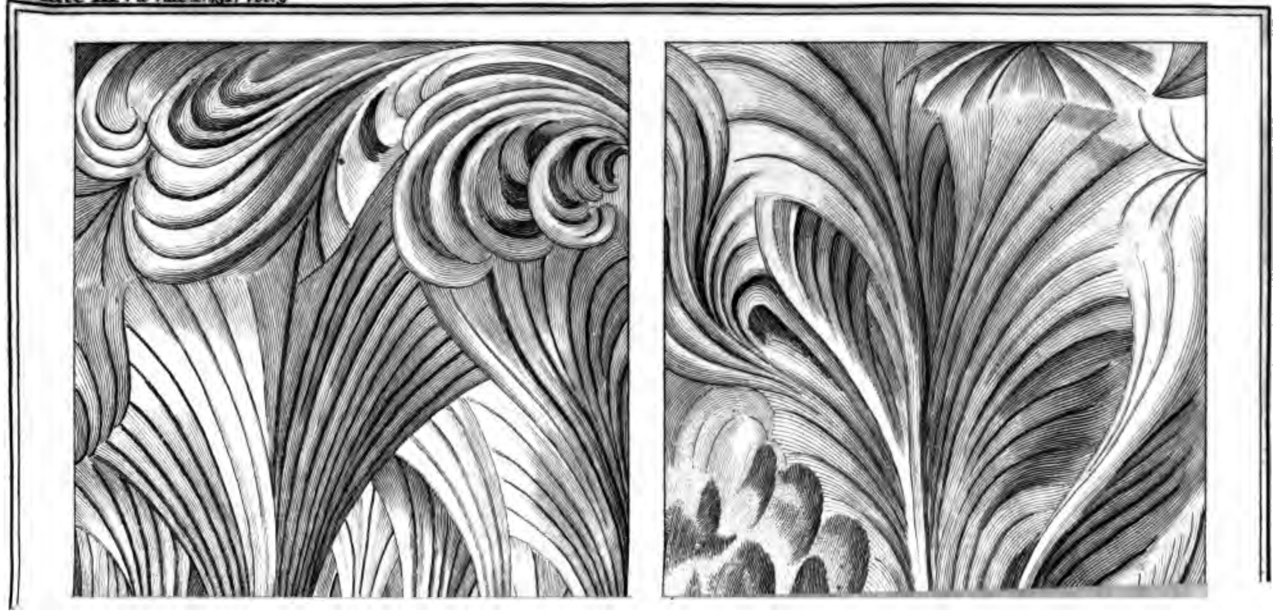
we

we shall find that it never holds truly to the same direction. Upon a level tract of ground covered with snow, I have observed, that its course is constantly in serpentine lines. The like may be seen in a field of standing corn, which plainly shews the obliquity of its motion; and, to a discerning eye, this irregularity is productive of that line of beauty, which communicates a certain elegance to all objects wherein it is found. The same kind of motion is produced in the waves of the sea; which form a pleasing spectacle by the variety of their undulations: and when a long pendant from the mast-head is flying aloft in the wind, it is never extended into a straight line, but has a curling motion which varies every moment. We may carry this so far as to suppose, that no two blasts of air from the creation of the world have been perfectly of the same figure. If we look into the reason of this, it must generally happen, that when two fluids which mutually penetrate each other are mixt together, there will be a certain resistance on the part of both, which will occasion a multiplicity of deviations from straight lines into curves. When wind blows through the air, it is not trajected across a free space, but insinuates

sinuates itself into a space already filled with other matter: consequently, when air impels air, a condensation must ensue; and the medium being elastic, the adventitious air, when deflected toward one side, will be turned off by the re-action of the air which is already in possession; and thus an oscillation will prevail, till the equilibrium is restored and the medium is at rest.

It is evident to sight that there is at all times an undulation in the air, even in a close room, by the motes that are seen to play about in the sun's rays, whenever the room is made dark for optical experiments: and though this motion is sometimes very occult and slow, yet it always subsists in some degree by day and by night. This motion may be the cause of some effects, which arise too slowly for us to perceive them till they are finished. It may assist in vegetation, to give form and flexure to plants according to the nature of the materials: and I think we have an obvious example of its influence in those elegant delineations which are formed on the panes of glass windows, when the air of the room, as it fluctuates with this subtile vermicular motion, deposits its moisture to be gradually frozen

Plate III. *to face P. 432. Vol. 9*



he coldness of the external air. No
ge of herbs or flowers can exceed the
lom and variety with which these lines
drawn. Several years ago I selected
of these as specimens, and copied them
ı paper*. The like elegant lines are
etimes to be seen on frozen mire; and
occur likewise in some crystallizations.
lution of sal ammoniac, and some vitri-
solutions, particularly of the blue vi-
, arrange themselves upon glass with the
: elegant foliage. I have never tried
these crystallizations, which I have sup-
d to receive their configuration from an
ılating motion of the air, will succeed in
ıo. Scheuchzer, in his Herbarium Di-
anum, gives us a curious figure of this
l, formed on the inner surface of a glass
ıe in the hard frost of January 1709, one
he years distinguished by a severe and
ng frost all over the more northerly
s of Europe: this delineation exactly re-
ents the muscus clavatus repens, or lyco-
um. His words upon it are these:
gura, rarissimi cujusdam in aere rigen-
ssimo motûs index, de quo aliorum ju-
cia audire malo, quam immaturum quid
"e pro-

* See plate III. fig. 1. and 2.

"e proprio proferre cerebro. Dignum utique "est hoc problema, quod subtilissimorum "philosophorum exerceat ingenia*." He goes, however, nearly as far as I have done, in understanding this phænomenon to have been occasioned by a subtile motion in the frosty air. In a severe frost, when Fahrenheit's thermometer was 17° below the freezing point, I poured a tea-spoonful of water into a substantial phial of flint-glass, nearly of the same coldness with the external air; and having shaken it to spread the water suddenly, the inner surface of the phial was instantly covered with stars of ice, almost as regular as if they had been drawn by design. I could never succeed in this afterwards: but it gave me an idea which I have retained ever since, viz. that there is a degree of expansive radiancy in every point of space, even when the atmosphere is affected with intense coldness.

On the Torricellian Tube.

The Torricellian tube, which is also called a barometer, because it measures the weight of the air, is an instrument now so universally

* See Herb. Diluv. plate VIII. fig. 1.

sally known, that I need not spend any words in describing it, and to avoid prolixity I must suppose my reader to understand it: if he does not, I must refer him to the first experiments of this kind described by the Academy del Cimento, and to the learned Mr. Cotes's Pneumatical Lectures, which explain it very particularly.

My design requires me to observe, that there are three different ways of making the experiment with a glass tube and mercury, all of which are of great importance in philosophy. The first method, and the most common, is to take a clean glass tube about 33 inches in length, and open at one end, which being perfectly filled with pure quicksilver and inverted into a cistern, and then elevated till it is truly perpendicular, the fluid subsides to 29 inches and a half, English measure, more or less according to the state of the air when the experiment is made. The space deserted by the mercury at the crown of the tube having no air in it, the external air presses up the mercury to supply the vacuity, till it sustains a column equal in weight to itself: for it is obvious, that the mercury endeavours to descend, by its gravity, with a force equal to that by which its

descent is prevented. This force, considered as a weight, is about 14 pounds upon every square inch: but the atmosphere being heavier at some times than others, the column of mercury rises and falls, from such causes, as give us notice of approaching changes of the weather: and hence the instrument is commonly used as a weather-glass.

The column of mercury thus sustained in the tube does not press upon the fluid in the cistern, nor weigh together with it, though it has a free communication: but its whole gravity goes with that of the tube which contains it. This may easily be proved, by adding a cap and a ring to the crown of the tube, and suspending it to the arm of a balance while it communicates with its cistern; which experiment, if I remember right, was first made by Sir Samuel Moreland. But it is scarcely necessary; because the fact is evident, when water is used instead of mercury. The water does not fall from the tube, though the open end is exposed; and consequently must add its own weight to the weight of the tube which holds it. As water is 14 times lighter than mercury, a column of water will rise into a void space 14 times higher than mercury, to make a counterpoise

to

to the atmosphere: and hence a common pump, when its sucker and valves make a vacuum at the top of the pipe, will raise water from a well nearly to the height of 34 feet: which principle is variously applied in hydraulic engines.

A second method of making the Torricellian experiment, is to fill a tube partially with mercury, leaving some air at the orifice, which, when the tube is inverted, will rise to the top; and, as the mercury subsides, that air will be dilated, till its elasticity, added to the gravity of the mercury, is a counterbalance to the atmosphere. When one inch of air is left at the open end of the tube, and the dilation of it is observed after the tube is inverted; it will be found, that if two inches of air are left, the dilatation will not be directly as the quantities dilated, but in another proportion. What proportion the dilatation observes in all cases, with respect to the quantity of air admitted, does not appear from any experiments I have hitherto met with, in all of which there is a perplexity and obscurity which I cannot develop to my satisfaction. Thus much appears from them, that the dilatation, *cæteris paribus*, does not

 observe

observe the same law in distant climates *: whence it seems probable, that the elasticity of the air is not always as its density, even supposing the heat also to be the same, as if there were some latent principle in the constitution of the air of countries far distant from each other, which affects its elasticity, and with which we are not at present acquainted. The experiments of which I am here speaking, seem to have been defective in this respect, viz. that the dilatations of the air were not simply examined as they ought to have been, but confounded with an uncertain proportion of the Torricellian vacuum. For the purpose of these experiments I would recommend a tube exactly of the length of the mercurial column for the time being, rather choosing to take it at the mean station: thus the dilatation observed would be purely a dilatation of atmospherical air, and we should be better able to judge of the law which the dilatation observes, and of the comparative elasticity in distant climates. It is likewise obvious, that an equal bore of the tube in all its parts, as far as may be, is necessary

* See Mem. of the Royal Acad. of Paris, Vol. iv. N°. 88.

necessary to the accuracy of these experiments.

There is yet a third way of filling the Torricellian tube, which differs essentially from the two former. If a tube of six feet long, perfectly clean and dry, is filled with the purest quicksilver, purged of its air to the uttermost by being boiled in the tube; the mercury thus prepared will not fall to the level of the common barometer when the tube is warily inverted, but the whole column will be sustained till it is made to fall by some shock or stroke upon the crown of the tube. How far this experiment may be carried, when made with every possible advantage, we cannot say: it has succeeded to the height of 75 inches.

Thus stands the fact, and as it is a fact of the utmost consequence in philosophy, let us give it due attention, and find out the reason of so extraordinary a phænomenon; in order to which, it will be necessary to premise the following lemmata.

Lemma 1. Quicksilver does not adhere to glass in the manner that water appears to do: a drop of water, as it runs down the surface of a vertical plate of glass, will be applied to the glass, and a part of it will remain

 there;

there; but a drop of quicksilver will roll off without the adhesion of the smallest particle. It is farther evident from experiment, that quicksilver tends toward quicksilver with more force than quicksilver tends toward glass; for which reason, while other lighter fluids are raised in a capillary tube of glass, quicksilver is depressed. Mr. De Luc, in his late experiments on the barometer, has actually detected a repulsion between glass and mercury, so that they are naturally disposed to separate; and the barometer is liable to an error on this principle, which, in accurate experiments, it is necessary to correct*. Therefore, if a column of this fluid is extended within a glass tube, it will contract itself and collapse into the cistern, unless some other cause should interfere.

Lemma 2. There is a medium more subtile than air, which yet is not subtile enough to pass through the substance of glass; at least not through glass of any considerable thickness. This is now so well known from many experiments in electricity, that it is not necessary to introduce a detail of experiments in this place for the proof of it.

Lemma 3.

* See Mr. De Luc's work on the Barometer, or Phil. Trans. 1771, No. 20, by the Astronomer-royal.

Lemma 3. Every body that is left at rest in a free space (or, where it has liberty of motion,) will not remain at rest, but will be moved by the principle of gravity, till it meets with some impediment, unless the cause of gravity should be suspended, or some superior force should act against it.

These things being admitted, which cannot be denied, inasmuch as they are all demonstrable by experiment, the fact in question will give us but little trouble. By Lemma 1, the column is not suspended by any attractive power in the glass of the tube: by Lemma 3, it does not remain at rest from the inertia of matter; therefore it is supported by the pressure of some medium; and as the air alone is not adequate to the effect, we must have recourse to another medium more subtile and more powerful than air.

The pressure of the atmosphere, in a larger sense, is the pressure of air and fire; it is not the pressure of air only, but the pressure of both, as we have already seen in a former part of this discourse. Sometimes these two act against each other, as in the case of the common barometer; and sometimes they conspire together, as in the case of the other

 extra-

extraordinary column. When a tube of glass is open at both ends, so that the atmosphere has access to each, the air then acts against itself, and the mercury falls by its gravity to a level with the cistern. When the upper end is closed, the air then acts at one end, and not at the other; and this is the reason why the mercury is sustained in the tube, till it is a counterbalance to the atmosphere. The same principle will suffice to account for the higher column. When the more subtile medium which can penetrate the mercury has possession of the cavity in the upper part of the tube, it acts at each end, and being thus a counterbalance to itself, nothing remains but the pressure of the air, which supports a column equal in weight to itself. But when that medium is excluded at the top by the perfect contact between the mercury and the glass, and cannot pass readily through the substance of the glass, it acts only upon the open end in conjunction with the air, adding its own force to that of the air, and producing a much greater effect of the same kind than the air can do when it acts by itself. Thus the extraordinary column is reduced to the same principle

ple with the ordinary; the one being from the pressure of air only, the other from the pressure of air and fire together.

As the ordinary and extraordinary column is sustained on the same principle, they likewise fall or subside on the same principle: if air insinuates itself at the lower end, which is open, it ascends to the top, and by its elasticity and expansion depresses the mercury; if more enters, it depresses the mercury farther; if a continual stream of air is admitted, it keeps ascending to the top till it has totally expelled the mercury. This is what actually happens in the other case; for when once the more subtile element is admitted to the top, by reason of the smallest separation of the mercury from the glass, it follows rapidly in a stream till it has got full possession, and reduced the column to a counterpoise with common air. To prevent this, it is necessary that the contact be absolute by means of a thorough purgation of the mercury from every particle of air which might rise up and occasion a separation.

I have been thus particular in the discussion of this case, because the experiment has always appeared to me as one of the most valuable in the whole circle of philoso-

phy;

phy; and therefore the learned reader will, I hope, excuse me for using more words than may seem necessary to those who would have been able to see through the whole argument in a much shorter form. This experiment puts us in possession of a principle, which in its application will be found almost as extensive as philosophy itself. The pressure of the atmosphere, as demonstrated and explained by the Torricellian tube, leads us to a satisfactory account of many phænomena, about which words had been multiplied for ages to little purpose. Here we have another force which comes in to our aid, and will carry us through other higher and more subtile phænomena, to which the air by itself is inadequate. Cohesion, with the action of such a medium as this, can be no longer difficult, and I think it may be explained, independent of this experiment*. And as to gravity, if a column of so great a weight does not fall, because this medium is not admitted to fetch it down, I can see no difference between that and the cause of gravity: to speak plainly, I am persuaded they

* See a Discourse on the Physical Cause of Cohesion in the Essay on the First Principles of Natural Philosophy, p. 144, &c. quarto edition; or p. 143 of the octavo.

they are but one thing; and I apprehend that much may be gathered from this single experiment, more than I have room for, or can see as yet, when it shall have been properly studied. To quicken the attention of the young philosopher, I shall shew him how this experiment has been regarded by some of the first philosophers in Europe, particularly Mr. Hugens, Dr. Wallis, and Dr. Jurin, who all considered it as an example of *another pressure*, different from that of the atmosphere, and far superior to it; a pressure from a fluid more subtile than air, and the same with the cause of gravity, which some call a *purer air*, some a *subtile medium*, but all mean the same thing in effect. The sense of Mr. Hugens, as represented in the Philosophical Transactions, is this: "Besides "the pressure of the air, which keeps the "mercury suspended at the height of 27 in- "inches*, (and of the truth of which we are "convinced by a great number of other "effects

* The reader is to observe, that the height of the barometer (I speak of its *mean* height) is differently expressed by different authors, because each describes it according to the statute measure of his country. With us it is 29½ inches: but French writers call it 27, &c. because the Paris foot is to the foot of London as 144 to 135.

"effects which we see,) there is yet *another* "*pressure* stronger than that, of a more "subtile matter than air, which, without "difficulty, penetrates glass, water, quick-"silver, and all other bodies which we find "impenetrable to air. This pressure, added "to that of the air, is capable to sustain "the 75 inches of mercury, and possibly "more, as long as it works only against the "lower surface, or against that of the mer-"cury, in which stands the open end of the "tube; but as soon as it can work also on "the other side, (which happens when strik-"ing or hitting against the tube, or intro-"mitting into it a small bubble of air, you "give way to this matter to begin to act,) "the pressure of it becomes equal on both "sides, so that there is no more but the "pressure of the air which sustains the mer-"cury at the ordinary height of 29 * inches. "The ingenious and candid author of this "solution acknowledges himself that it doth "not so fully satisfy him as not to leave "some scruple behind; but then he adds, "that that keeps him not from being well "assured

* Here the English translator seems to have forgotten himself, and put the English measure instead of the French, which he had used before.

" assured of that *new pressure*, which he
" hath supposed besides that of the air, by
" reason of the experiment already alleged,
" as of two others which he subjoins to the
" same effect." The whole paper is very curious, and worthy of the reader's perusal *.

Dr. Wallis, in some remarks on this solution of Mr. Hugens, has the following observation: " If this, which we call gravity,
" should chance to be not a positive quality
" or *conatus* of itself originally, but only the
" effect of some pulsion or percussion from
" without, which possibly may be the case,
" and principally from the spring of the air
" about us, then while this pulsion and per-
" cussion is wanting, (however obviated,) the
" bodies accounted heavy will not of them-
" selves begin to fall."—" He might also, (continues Dr. Wallis) " suitably enough to
" his own hypothesis, have so explained
" himself as to allow his more subtile parts
" of common air to penetrate quicksilver,
" but not glass; and, therefore, in case of
" room for it at HD, (the top of the tube,)
" it might, through the stagnant quicksilver,
" pass upwards, and thence exert its spring †."

In

* See Phil. Trans. Abr. by Lowthorp, vol. ii. p. 25, &c.
† *Ibid.* p. 26, 27.

In this he has hit upon the very idea, which is now much more obvious to those who are acquainted with the present state of electrical experiments.

Dr. Jurin, in a discourse on the ascent of water in capillary tubes, inclines to the same opinion, admitting a pressure besides that of the air, and referring to the present experiment, and some others, for the proof of the principle. "How far (says he) this cohe-
"sion (of the water in capillary tubes) may
"depend on the pressure of a medium sub-
"tile enough to penetrate the receiver, (or
"the other parts of the apparatus,) is worthy
"of consideration. This explication seems
"to be favoured by the following experi-
"ments: first, the famous suspension of
"mercury purged of air to the height of 70
"or 75 inches, in the Torricellian tube in
"the open air: to which we may add the
"sustaining of mercury likewise purged of
"air within the exhausted receiver, as relat-
"ed by that learned and successful promo-
"ter of natural knowledge, Mons. Papin,
"in his Continuation du Digesteur. But
"we must not omit the experiments made
"by the famous Mons. Hugens, and describ-
"ed by him in the Philosophical Transac-

"tions, N°. 86, of the cohering of polished "plates, with a considerable force in the ex- "hausted receiver; as likewise of the run- "ning of water and mercury, when purged "of air, through a siphon of unequal legs "in the vacuum; all which he accounts for "from the same principle, and much in the "same manner as we have used for explain- "ing the experiment above. As to the ex- "istence of such a medium, I shall content "myself to refer to what has been said by our "illustrious president in the queries at the lat- "ter end of the last edition of his Optics*." Thus far Dr. Jurin, whose sentiments agree in this matter with those of the Lord Brounker, Mr. Hugens, and Dr. Wallis, and have since his time been much farther confirmed by the subsequent discoveries of later philosophers, which have now left us in no doubt about the existence and active force of such a medium as was formerly the subject of queries and hypothesis; and with these discoveries our mode of philosophising about many phænomena of nature must alter. However, such are the vicissitudes of human knowledge, that in this we are only returning to what we had rejected.

On

* See Phil. Trans. Abr. vol. v. p. 191.

On the Use of the Barometer in measuring Elevations.

Whatever the specific constitution of the air may be in itself, the higher parts, as in other fluids, must act upon the lower, and those that are lowest must be subject to the greatest pressure.

The specific gravity of water to air, is as 800 to 1, supposing the barometer to be at 30 inches, and the air at a mean state of heat and cold *; and the specific gravity of mercury to that of water, is as 13.5 to 1; therefore the specific gravity of mercury is to that of air as 10800 to 1, consequently a cylinder of air of 10800 inches, or 900 feet, will be equal to an inch of mercury. If the air were of an equal density throughout, like water, the barometer, when carried upwards, would sink an inch for every 900 feet of ascent, and the atmosphere would be five miles high. But air being an elastic fluid, its expansion increases as the incumbent weight decreases; that is, the upper parts are more rarefied than the lower; and the space

* See Phil. Trans. Abr. vol. ii. p. 15.

space of air answering to an inch of mercury, grows continually greater as we ascend higher from the earth.

Learned geometers have considered in what proportion the air will be rarefied at different elevations above the earth; and they find, that if the elevations are taken in an arithmetical progression, the density will decrease in a geometrical progression, and consequently, that the logarithms of the densities will be reciprocally as the elevations. But the weight of the air being as its density, and the height of the barometer being proportional to the weight of the air, it follows that the logarithms of the heights of the mercury are reciprocally as the elevations *. Hence we have a rule for measuring elevations by the barometer; for if there is a known ratio between the elevation and the density, the barometer, so far as it measures the density, will measure the elevation; and thus we have a compendious method of finding the altitude of mountains, with little more trouble than that of ascending them.

The order of the calculation is this. First, to find accurately what elevation is required to make the barometer fall one tenth of an

 inch,

* See Phil. Trans. Abr. vol. vi. part ii. p. 45.

inch, (or any other quantity,) which let us suppose to be 86 feet: and let us also suppose that this is done when the barometer, at the lower station, is at 29.5 inches at the level of the horizon, that is, when the atmosphere is at a middle state. Then say, as the difference between the logarithms of 29.5 and 29.4 is to 86 feet, so is the difference between the logarithms of 29.5 and 27.5 (or any other height of the barometer in inches and tenths of an inch) to the number of feet required.

On this principle tables were composed many years ago by two learned mathematicians of our own country, Dr. Halley and Dr. Nettleton, and by others in France. And thus far the calculation is very easy. But all observers were sensible of some irregularity in the theory on account of the uncertainty of the air, which it was very difficult to provide against. In conclusions which depend on mathematical reasoning and actual observation, it is generally easy to approximate; but, to attain to accuracy and precision, is difficult. Every common navigator can find his time by the sun to a minute or two: but to find it to seconds requires the best instruments, and a more laborious

borious calculation: so that while the former may be executed at the expence of a few shillings, the latter will require an expence of many pounds.

Two difficulties arise to disturb the theory; one from the imperfection of the instrument, the other from the uncertainty of the atmosphere. At different elevations the temperature of the air alters; and the greater elevation being generally attended with a colder temperature, this occasions a contraction of the mercurial column, so that the barometer falls lower than it ought to do, and observation gives an elevation greater than the true. And as the elasticity of the air alters with heat and cold, the density of the air cannot be truly inferred from its absolute pressure: and thus we are liable to a second error. More heat, at the same elevation, will increase the elasticity of the air, and the pressure being greater than it ought to be by the theory, the elevation will be found too little. More cold will diminish the elasticity, and then the elevation (which commonly happens) will be found too great. The barometer is liable to another error: for in the common upright tube the mercury never rises so high as it ought to do, from a

repulsive effect of the glass upon the mercury. But this is corrected by a siphon-tube instead of the straight one; for thus there are two repulsions which correct one another. Some other niceties might be mentioned, concerning the different degrees of expansion in glass and mercury under the same degrees of heat and cold.

These are the difficulties in measuring altitudes by the barometer, which of late have exercised the ingenuity of Mr. De Luç, a learned and philosophical native of Geneva, to whom the public is much indebted for some valuable improvements in this part of philosophy, which are the fruit of great labour and attention. His work is too large and complex for me to attempt a particular account of it: and his improvements have already been represented to great advantage by two very learned members of the Royal Society, Mr. Maskelyne the Astronomer-Royal, and the Rev. Dr. Horseley, who have given two excellent papers in the Transactions upon the new Theory and Practice of Barometrical Mensuration*; to which I must refer the learned reader.

From the ingenious Mr. Brydone's observations

* See vol. lxiv. part. i. N° 20, and 30.

vations of the barometer, in his Travels into Sicily, which I suppose are very near the truth, I have calculated the height of Mount Etna, according to the old and new method: and by every rule I can apply, I can make the height of that mountain but a trifle more than 2 miles; whereas by geometrical observation it is more probably 3 miles high, or nearly so, if accounts are true.

I take Dr. Halley's observed difference of the barometer at the top and bottom of Snowdon Hill, with its height as found by geometrical mensuration: with this I compare Mr. Brydone's difference at the top and bottom of Etna; and the result is as follows:

	In.	Tenths.		
Barometer at the level of the sea,	29.	9	log.	14756712
Barometer at the top of Snowdon,	26.	1	log.	14166405
Difference				590307

Height of Snowdon, taken geometrically, 1240 yards.

	In.	Tenths.		
Barometer at the foot of Etna,	29.	5	log.	14698220
Barometer at the top of Etna,	19.	5	log.	12900346
Difference				1797874

Then we are to say,

As the first difference 5903 (rejecting the two last figures as superfluous) is to 1240 yards; so is the second difference 17978 (rejecting the two last figures as before) to the

 number

number of yards in the height of Etna; which appears to be 3776, or 2 miles 98 fathoms.

By the new method, the difference between the two last logarithms is to be taken as before; and when that difference is divided by 1000, (which is done by changing the three last figures into decimals,) the quotient expresses the number of English fathoms; which is 1797. The correction being made for the contraction of the mercurial column, by $\frac{76-23}{2} - 40 = 8$ degrees of Fahrenheit's thermometer, according to Mr. De Luc's rule, applied to Mr. Brydone's observation, the number is diminished by about 33 fathoms. And the same being farther corrected according to Mr. De Luc's equation for the temperature of the air, we have nearly 33 fathoms, as before, to be added to the last corrected number; so that the number of fathoms is 1797, as at first; and differs but 21 fathoms, in more than 2 miles, from the number according to the old method: and it is probable, that, in so great an elevation, the error from the uncertainty of the air will generally exceed this difference. As there is reason to suppose, upon other considerations, that Etna is much above 2 miles in

height, Mr. Brydone suspects that the barometer does not agree with the theory in very great elevations; particularly, that, in the superior elevations, when we get above the region of vapours, the spaces corresponding to given differences in the mercurial column are greater than according to the rule. And I must own it appears probable, that, in the lower elevations, while you are within the region of gross vapours, the column ought to diminish much faster than in the superior elevations; and that the same law cannot truly be applied to both*. I cannot venture to pronounce how this may be, without farther and more accurate observations. I must therefore content myself with adding some notes relating to the system of the atmosphere, for which I am chiefly indebted to the learned observations of Dr. Horseley, who has gone deeper into this subject than any writer before him.

1. It is probable that the elasticity of the air may be affected by other causes beside heat, such as humidity and electricity.

2. If Mr. De Luc's formulæ, expressing the

* Omnis aer, quo proprior est terris, hoc crassior; quemadmodum in aqua et in omni humore fæx ima est; ita in aere, spississima quæque desidunt. Senecæ Nat. Quæst. 4. 10.

the effect of temperature on the air's elasticity, are universally true, it will follow, that there is a certain temperature at which the air would totally lose its elasticity, and that elasticity owes its origin to heat. I thought I saw this consequence twenty years ago; and placed the supposed temperature, at which this would happen, at about 300 degrees below the freezing point*. Dr. Horseley, from the *formulæ* of Mr. De Luc, places it at 409; but denies the inference, and seems rather to suppose (if I do not misunderstand him) that such a consequence does not obtain in nature; which is the more probable opinion. When I thought formerly upon this matter, we had no expectation that nature or art would ever exhibit a degree of cold any thing like to what experiment hath since discovered.

3. The diminution of the air's density, as we ascend from the earth's surface, is subject to a limit, and the atmosphere may be of an infinite height: though at that height Dr. Horseley reduces its comparative volume to the 100^{th} power of 3069. This is the case when the subject is considered mathematically. When it is considered physically, he

* See the Essay, p. 319.

he is so candid as to allow, that we have no data from experiments to limit the height of the atmosphere. I apprehend there is a certain height at which the matter of the heavens has no immediate reference to our earth as a part of its atmosphere, but is independent of the earth and all its appendages as it passes through the heavens in its orbit; somewhat after the manner as those waters of the sea are independent of the ship, which lie without the limits of her wake. When the air has no longer any reference to the earth as an atmosphere, and has no sensible gravitation towards the earth, it is questionable whether it would have any effect on a barometer, whatever its density might be. If some air were brought down from the top of Etna, according to the *second* method of making the Torricellian experiment above described, and its absolute density were properly compared with the air below, it might give us some farther light into this interesting part of the subject.

4. It is possible that the density of the air may increase above, while it is diminished below; and that the condensation of the superior part will follow from the rarefaction of the inferior by heat. It may sound like a paradox

paradox that heat should condense; but it is true by necessary consequence. When the heat increases near the earth, the air is there expanded into a larger volume; and having no liberty below, where the earth is opposed to it, the redundant quantity must go upwards, and bring the whole nearer to an uniform density.

5. If at any height above the surface of the earth, an increasing heat diminishes the density of the air in the same proportion as it increases its elasticity, a barometer will there be *stationary**. At lower heights it will sink, and at greater heights it will rise. This case Mr. De Luc actually met with, and was much surprised at it. When the heat of the day has been increasing, a barometer has sunk at the foot of a hill, while another at the top has risen. Scheuchzer was perplexed formerly on the same occasion: he found his barometer rise at the higher station, while it sunk at the lower, contrary to the rule; and he endeavoured to account for it from the greater elasticity of the

* This is the very case I have mentioned under another form in a foregoing section, on the Elasticity of the Air. See law 5.

the purer air*. This may teach us how subject we are to unexpected difficulties in settling the theory of the atmosphere; and that we should not build too much on inferences and calculations, which, when applied as general rules, will lead us into errors. The superior regions of the air, above the highest mountains, where no experiments have yet been made, may be subject to certain affections of which we have no knowledge, and which, if known, would very much interrupt some of our conclusions†. There are two circumstances, which of themselves incline me to believe, that, after the many useful and curious discoveries which have been

* See It. Alp. Sec. p. 15, 33.

† Some learned astronomers have been inclined to believe, from the observation of certain appearances in the heaven, that there is matter capable of reflecting the sun's rays at a height above the conical shadow of the earth's orb. Mr. Boyle gives us the following passage from Ricciolus, concerning an observation made by Emanuel Magnen at Tolouse—"Vidit ab horâ undecimâ post meridiam usque ad "mediam noctem, lunâ infra horizontem positâ, nubeculam "quandam lucidam prope meridianum fere usque ad zenith "diffusam, quæ consideratis omnibus non poterat nisi a sole "illuminari; ideoque altior esse debuit tota umbra terræ." Vid. Boyle on the Spring of the Air, book ii. ch. 13. I am in doubt whether this might not be something of kin to the aurora borealis, not then so well understood.

been made, the atmosphere is yet but imperfectly understood: the one is the violent force of the wind on the top of Etna, above the region of the clouds, where the air, by the barometer, seems to have lost one third part of its density: the other is the sounding of explosive meteors from the height of 60 or 70 miles and upwards in the air. In this region, where the air, by calculation, is much rarer than the best vacuum of an air-pump, combustible matter is collected in great abundance, which must be derived from the earth, as the pure matter of the heavens cannot be supposed to furnish it out of itself. In this region, inflammable matter explodes and burns with a vivid light; though the matter of lightning is dissipated in a vacuum. And, what is most surprising, sound is thence transmitted to the earth; which, as experiment shews, cannot be communicated without the intervention of the air as its vehicle, or the vibrations of some continuous solid body. I saw a meteor myself in the year 1766, which, from the accounts of it in the public papers, compared with my own observation of it, was above 45 miles high in the air, and exceedingly bright. But most extraordinary is the account given by Dr. Halley

Halley of a meteor seen all over England; which, by a calculation sufficiently accurate, was 70 miles high; as bright as the sun; and the explosion of it, which was as loud as a broadside of cannon, was heard all over Devonshire, Cornwall, and the neighbouring counties, and shook the houses and their furniture, as if great guns had been fired near at hand.

The learned author, who drew up the account of this meteor, could find no way of reconciling it with the received theory, but by supposing that the magnitude of the explosion might perhaps compensate for the extreme rarity of the medium. But the question seems still to remain: for how can sound, of any magnitude whatsoever, be communicated from a region in which there can be no sound? According to the common idea we have of it, sound is occasioned by a stroke upon that air which is contiguous to a sonorous body. Where there is no air to receive such a stroke, there is consequently no sound; and where no sound is, none can be communicated. As to the communication of sound through solid bodies, (of which we shall have occasion to speak hereafter,) that can have no place here. And therefore

I do look upon this case, and others like to it, as an argument, that *universal* conclusions have been formed too hastily upon *particular data*; and that the theory of the atmosphere, specious as it may appear, and useful as it may be found under proper restrictions, is still capable of farther correction.

Of Fixed Air and Elastic Vapours.

The term *fixed air* has been used to denote the elementary substance of air, changed from its volatile and elastic to a fixed and quiescent state; during which it is attached to other bodies, and gravitates with them; but it may be again detached from them by the action of fire, the mediation of water, &c. so as to reassume the form of elastic air.

The instances are very numerous in which air is thus detached from bodies. When drowned animals have lain under water till they putrefy, a decomposition of their parts is the consequence, and they are found bloated with the air which is separated from them, and become elastic. When dry peas are soaked in water, they swell, and discharge a great quantity of elastic air. And food, while

while it is digesting, (especially in a weak stomach,) often yields a flatulent spirit, which troubles the intestines in the form of wind. Spring water, when exposed to the air in warm weather, but especially if it is exposed to the sun, discovers multitudes of air bubbles, which arise from the fluid, and attach themselves to the sides of the vessel. Mineral waters, as the Seltzer, Pyrmont, &c. yield more than common spring water, and are supposed to derive much of their virtue from the aerial spirit with which they are impregnated. All fermented liquors, as wine, beer, cyder, abound with it, and are supposed to contract it in the act of fermentation, when the parts are opened and decomposed; in which respect, fermentation resembles putrefaction.

Sometimes it happens that ingredients of contrary qualities, when mixed together, decompose one another; and in the act of decomposition, discharge a flatulent elastic spirit. This is the case when acid juices come into contact with alkaline earths or salts; and the air that is generated by such a mixture is so friendly to the stomach, that a saline draught, in the act of its effervescence, has long been recommended as a remedy against

against a nausea and vomitings; with an antiseptic virtue, which is of great service in fevers.

Many dry substances yield air with the application of fire. When the tartar of wine is urged with fire in a retort; an explosive spirit is raised from it, which, if confined, will burst the vessel. But the most explosive spirit of all is separated from fired gunpowder, the effects of which are universally known. When saltpetre is laid in the naked fire, it burns exceedingly bright, and this spirit comes from it in a continued blast till the substance is consumed. Sea coals, as they are burning in the fire, are frequently seen to emit a powerful blast of air for a considerable time. It would be difficult to enumerate all the bodies, as well fluid as solid, from whence air may be produced by the force of fire. I have driven an explosive blast of wind, with an hissing noise, into an exhausted receiver, by applying the heat of a charcoal fire to a bolt-head of glass, containing some linseed oil, and the mercurial gage within has been considerably raised by it.

The study of fixed air has been much cultivated and extended of late years; but the subject

subject is not new. Van Helmont was acquainted with the principal experiments relating to it. He knew that an explosive spirit is separated from gunpowder, from fermenting liquors, from vegetable substances acted upon by fire, from calcarious earths, and metals in effervescence with acids. To the separation of air from digested or corrupted aliment, he imputes that flatulency with which the stomach is troubled when the digestion is weak; and from the same principle he accounts for the swelling of dead bodies under water*. Paracelsus thought that the spirit which discovers itself on these occasions, is the same with the air we breathe, reduced to its elementary parts, and fixed in other bodies. But Van Helmont rather took it for an extemporary vapour, consisting either of humidity rarefied, or of the subtile parts of an

* On this principle murders have been frequently discovered, by the buoyancy of dead bodies, supposed to have been concealed under water. I was informed by my father, who was an eye-witness of the fact in London, that the body of a person who had been poisoned, swelled so much in the earth after its burial, as to burst the coffin, and raise the ground, which was observed by some children at play to be in motion, and they alarmed the neighbourhood. The corpse, when taken up, was distended to a monstrous size, and horribly offensive.

an acid, expanded with the volatile parts of alkali *. Mr. Boyle also made many experiments on what he calls *artificial air*, generated from vegetables, and fermenting chemical mixtures. His air-pump, then lately come into use, enabled him to pursue this inquiry with more advantages than Van Helmont. He found that factitious air suddenly generated, would, in many instances, be as suddenly destroyed †.

This subject was afterwards taken up and examined more minutely by Dr. Hales, who has given a particular detail of his experiments in his Vegetable Statics, and has left us this doctrine: that air may be raised by fire and other means from solid bodies to a permanent expansion, and that the air so generated is the same true elementary substance with the air we breathe: that the force of gunpowder, and the *pulvis fulminans*, is owing to the expansion of the air which is separated from them in the explosion ‡.

But

* See Essais Chemiques et Physiques par M. L'Avoisier.

† See Book III. cap. iii. art. 12.

‡ Mons. L'Avoisier, the French chemist above mentioned, invented a sort of fluid gunpowder, composed of spirit of nitre and spirit of wine, which, when distilled together in a retort, yielded incredible quantities of air. See his Essays Chem. and Phys. in the English translation, p. 122.

But he observed, that this air is not always permanent; that it seemed to shrink and alter its dimensions, and even to disappear without any visible cause. He seemed to be uncertain what effect is produced on air by bodies burning in it. Boerhaave repeated many of these experiments, and laid it down as the result of all his inquiries on this subject, that fire separates from all bodies, whether by combustion, fermentation, putrefaction, or distillation, an elastic vapour; and, consequently, that this aerial matter resides in bodies, but in such a manner as not to produce the effects of air, till it is detached from them, and is joined to other parts similar to itself. Mr. Venel, of Montpelier, made experiments on the spirit which resides in mineral waters, particularly the Seltzer water, and found it amounted to one-fifth of the bulk: that when this spirit is discharged, the water returns nearly to the condition of common water. This led him to attempt an artificial combination of air with water, which he effected by confining the air raised from the effervescence of an acid with an alkali in the same space with a proper quantity of water; under which circumstances the water imbibed it, and became

 more

more strongly impregnated than the Seltzer water by the chemistry of nature, insomuch that the air absorbed amounted to one half of the bulk of the water.

Instead of giving a larger detail of these experiments, which have been abundantly multiplied, I shall here observe, that the true air of the atmosphere is best distinguished by its criterion of permanent elasticity. This air, kept in a condensed state for twenty years, has been found at last to exert the same force as at first, which shews it to be a true elementary substance. It will also bear to be in contact with water, without undergoing any change. The mock-air, or elastic vapour, which assumes the form of air, is temporary, and loses its elasticity by some kind of precipitation. Perhaps it is composed of minute bubbles or vesicles, too small for observation, which burst and expire by degrees like other grosser bubbles, and with this the volatile matter subsides and disappears. Fire gives a temporary elasticity to the vapour of water, but as the heat abates, the vapour collapses and returns to its natural condition of water. Other matter, more subtile than water, may be distended in like manner, and preserve its elas-

ticity

ticity longer. We may therefore say of all these factitious airs, that they are nothing but æther combined with expandible matter. So many conjectures have been formed on experiments of this kind, with so many transitions from natural air to artificial, and from artificial to natural, that M. L'Avoisier, who reviewed them in the state they then were, observed, with some reason, that the subject was in great perplexity. Others have preferred a complaint against the experimenters on fixed air, for making as many sorts of fixed air as there are bodies that yield it; which can answer no end but that of increasing the natural obscurity of chemistry, when there is no necessity for it. However, many curious, and some very useful experiments have been published, which have greatly improved this part of philosophy, and given us a farther insight into the natural history of the air; on which consideration, they who have set the facts before us are entitled to the thanks of the public, whether they have been equally successful or not in their reasonings upon them; and I must be so just as to own, that I have read few pieces of experimental philosophy with more pleasure than Dr. Ingenhouz's late treatise on

the reciprocal effects of air and growing vegetables on each other. I shall therefore proceed to describe the several modifications of air, under the names which modern authors have given to them.

Inflammable air is so called, because it takes fire with the flame of a candle, and, if confined, will go off with a violent explosion. It is the production both of natural and artificial chemistry: it comes out of the earth, as a cold blast, in coal mines; and is therefore by some called *spirit of coals*: it may also be obtained by distilling coals in a retort. Some of this air was sent up to the Royal Society by Sir James Lowther in bladders, from his coal mines at Whitehaven, which preserved its elasticity and inflammability. In Persia there is a tract of ground, where, if the earth be ever so little turned up, and flame applied to the cavity, the vapour that rises up will take fire; and if a tubular cane is stuck in the earth, the flame will burn from the mouth of it, without consuming the cane itself*. If the muddy bottom of a ditch or stagnant water in marshy ground is stirred up with a pole in the night, the air that rises up to the surface will be seen to

* See Phil. Trans. Abr. vol. x. p. 677.

to take fire when a lighted paper is applied to it. This is a curious and a very practicable experiment. Inflammable air, or something like to it, is also produced in the bodies of animals. A candle in the hand of a butcher has been known to give fire to the vapour from the bowels of an animal while they are yet warm. If we may trust to history, says Boerhaave, the humours of the bodies of animals have been sometimes carried to such a degree of oiliness and subtilty, as to catch, like alcohol, a weak pure flame. To this effect we have instances of men, whose fumes, as they perspired, would kindle around them: and Helmont even speaks of a man, whose wind, &c.* Inflammable air is artificially produced from a mixture of oil of vitriol, water, and iron filings. A strong ebullition appears; and if the vapour is received in bladders from the neck of a glass phial, it will burn and explode like the inflammable air from a coal-pit. This experiment was first communicated to the Royal Society by Mr. John Maud, in the year 1736, to illustrate the phænomenon of Sir James Lowther's bladders from the coal-pits†. This

* See Boerhaave's Chemistry, by Shaw, vol. i. p. 335.

† Phil. Trans. Abr. vol. ix. p. 396.

proves that a subtile sulphur is the inflammable principle in this sort of air, because sulphur decomposes into an inflammable oil and an acid, out of which it may also be artificially composed. When inflammable air, raised from these ingredients, is inclosed in a vessel of brass, it will take fire with the electric spark, and go off with an explosion like gunpowder; for which experiment an apparatus is purposely contrived, with proper glasses, for producing the air, and a brass phial, called the electric pistol, whose neck is formed into a cylinder or barrel, and stopped with a cork. The damps which take fire in coal mines, and produce such terrible effects, are composed of inflammable air; and some effects may possibly be occasioned by it at great depths under the earth.

Nitrous Air is obtained by the action of a nitrous acid, or aquafortis, on mercury, brass, copper, &c. The usual form of obtaining it, is to let the menstruum work on the metal in a phial, from the mouth of which a bended tube of glass conveys it as it rises into the mouth of an inverted phial of water.

This sort of air will incorporate with the common air of the atmosphere, without increasing the bulk of it. One part of nitrous, with

with two parts of common, will be lost in the mixture; and though the nitrous air has the gravity of common air, it adds nothing to the weight of the mass, of which it makes a part. If this be the case, it is most probable that what is called nitrous air, is a vapour which is precipitated by its mixture with common air. As to the lessening of the volume upon this mixture, it is no uncommon thing for two ingredients, when mixed, to take up less room than when separate; indeed few mixtures are of the same bulk with the parts of the composition. Spirit of wine and water mixed, are contracted in their dimensions; and the fact may be accounted for from an alteration which takes place in the medium that is seated in their pores; sometimes air is discharged by the mixture, sometimes fire. Some such thing may be supposed to happen when natural and artificial airs are mixed together. The variety in such a case will be endless, as the temper of the factitious vapour is different.

Fixed air is air impregnated with the parts of earth and vegetables: it is that vapour which arises from the fermentation of a vitriolic acid with calcarious earth or stone,

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and from fermenting substances. There is an unctuous clammy vapour, which is generated from the stum of grapes, when they lie mashed together in the vat, which puts out a candle when dipped into it, and would be fatal to an animal if it were taken into the lungs. The wort of malt liquor, while it is working, is covered with the like vapour, to the height of 8 or 9 inches. Pits and cavities in the earth, where heterogeneous matters have lain together, and been long covered up, are apt to produce that stagnant vapour which is called *mephitic*, and is fatal to those who descend into such places unawares, and take it into their lungs, where it occasions a spasm, which stops the act of respiration.

Pliny tells us of many places where such a noxious air was naturally produced in the earth—"Spiritus lethales alibi aut scrobibus "emissi, aut ipsi loci situ mortiferi: alibi "volucribus tantum, ut Soracte vicino urbi "tractu; alibi præter hominem cæteris ani- "mantibus: nonnunquam et homini, ut in "Sinuessano agro et Puteolano. Spiracula "vocant; alii Charoneas scrobes, mortife- "rum spiritum exhalantes. Item in Hirpi-

"nis Amsancti, ad Mephitis ædem, locum "quem qui intravere moriuntur *."

The grotto Del Cani, near the city of Naples, has long been famous for a mephitic vapour, which floats within a foot of the surface. For a particular and entertaining account of it, I may refer to the travels of Mr. Addison, who himself tried several experiments in it †.

Phlogisticated air is air charged with phlogiston. This change is made in common air, by the addition of a sulphureous or excrementitious oily vapour, which the air contracts, either from the fumes of combustible bodies, such as the flame of a candle, the fumes of charcoal, &c. or by being returned from the lungs of an animal in respiration. The air derives this principle likewise from the

* Plin. lib. ii. cap. 93. I find nothing authentic in regard to the signification of the word *mephitis*. Scaliger, in his notes on Varro, takes it for an Etruscan word. The ancient Etruscans used the Aramitish language; and נפח in the Syrian, is *to blow* or *breathe*. The term was probably thence borrowed to denote a noxious air. *Mephitis* was applied as a proper name to Juno, and distinguished her as the divinity that presided over stinks and poisonous exhalations. Thus the heathens had their sweet and their stinking Juno, as they had their celestial and infernal Diana.

† See Addison's Works, 4to. vol. ii. p. 80.

the calcination of metals, in which operation the fire expels that native sulphur, of which all metals partake in some degree, and which is the vinculum that gives coherence to their parts. Air thus impregnated is not inflammable, but is become totally unfit to support either burning fuel, or the life of an animal. There is a certain chemistry in nature, by means of which air thus fouled is purified and restored to its natural state, of which we shall see more hereafter.

Dephlogisticated air is air regenerated in a pure state without any mixture of the phlogiston, and was lately found by Dr. Priestley to be a fluid more simple than the best atmospherical air. It was observed to sustain the life of an animal, in a close vessel, four or five times longer than common air. A candle also burns more clear and bright in it, with a vivid and sparkling flame: it is raised by fire from metals that have been calcined, especially from calcined mercury and red precipitate; and being thus pure and wholesome, though produced from matter which is highly poisonous, it cannot be supposed to borrow any thing from the subject. This air is called dephlogisticated, in opposition to the phlogisticated; but *new air*, which

which never had any of the phlogiston, can scarcely be said to be dephlogisticated.

When saltpetre is deflagrated in a naked fire, or by the application of any burning fuel, the air which comes from it is soiled with phlogistic vapour; but if it is fired by heating in a clean vessel, it yields a pure air, like that from the calces. The same pure air is sometimes obtained from waters, and arises plentifully from growing vegetables. In short, it seems to be pure natural air, without the adulterations to which the atmosphere is subject; particularly without that adulterating ingredient, sulphur, which appears under so many different forms, and which, as we have reason to think, lessens the salubrity of the air wherever it is found, especially if any degree of putridity is combined with it.

No reason to doubt that Air is a real Elementary Substance.

Experiments on airs of all kinds have been very much multiplied of late years, and multiplicity is apt to beget confusion. Hence a sort of scepticism hath arisen concerning the element of air itself, which seems in a

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manner to have been sunk and lost in a cloud of new distinctions. Sometimes it is conjectured that air is made of water, sometimes of nitre, sometimes of earth. When it is regenerated from ingredients, none of which seem capable of yielding it, the very existence of air as an element has been brought into question. But it appears from experiment, that fire expands and sustains another substance grosser than itself, which no process can precipitate from it. This substance is not earth; for that element is not volatile. It is not fire; because it is something expanded by fire, and which counteracts, by its pressure, the motions of fire. It is not water; because, in exhausting a receiver of its air, we leave the water behind, and draw out something else: which being not fire, nor earth, nor water, is therefore air, properly so called; the element by which we live and breathe; a simple fluid, with an etherial nature proper to itself; and which, though it may be disguised and adulterated, is distinct from all temporary vapours.

That there should be some difficulties and misunderstandings about it, is scarcely to be wondered at, when the relation between fire and air has never yet been studied, nor

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so much as thought of, so far as I can find, by modern experimenters, who apply rather to earth and to water than to fire, to account for the properties and transformations of air, to which nothing but fire can be adequate. We shall, I hope, obtain some light into this affair, as we proceed to consider the provision there is in nature, for changing, purifying, and replacing the air which is either consumed or spoiled in the common course of things.

Foul Air, how purified.

When air is become foul by the accession of any offensive fumes, it may be cleansed like other things, by washing it in water. If some such air is confined in a vessel, and agitated together with pure water, it will leave its foulness behind, and by degrees be rendered sweet and respirable. Lime water is particularly efficacious in restoring to purity, air which is infected by respiration*. Running

* This may be owing to the affinity between fixed alkalies and sulphurs, by means of which they readily unite. See the clii. process in Boerhaave's Chemistry. Alkali purifies metals on the same principle, by uniting with their sulphur.

Running water has an effect upon the foul air which is contiguous to it, and renders it more wholesome. They that work below the earth, in mines, find they are generally sure of having a pure air to live upon, if they are but near a vein of water that can be turned into the works. All the running waters of the earth have the salutary effect of improving the constitution of the lower air: the daily motions of the tides, and the occasional agitations of winds and storms, all serve to the same good end, by washing and purifying the air that is contiguous to them, and keeping it fit for the support of animal life; and the breezes from the sea bring the air thus washed and purified to the land. The rains that fall contribute to the same effect; and we are immediately sensible of a returning freshness and vigour to the air, when it is washed by the descent of a shower through it after a time of drought. So effectual is rain for this purpose, that the most deadly blast which traverses the desert, and destroys man and beast, becomes qualified and harmless if a shower falls across it in its progress.

Growing

Growing Vegetables purify Air.

The growth of vegetables, both by land and water, has likewise a wonderful effect in correcting the foulness of the air; and this, not only by purifying what is bad, but by yielding a store of new matter continually for the recruiting of the atmosphere. Dr. Priestley found, by experiment, that plants thrive surprisingly in a putrid air; and the subject was enlarged upon with great judgment in an annual oration by Sir John Pringle. Hence we have one of the most elegant discoveries in experimental philosophy; namely, that plants and animals act reciprocally on air for each other's advantage: the breath of animals corrupts the air; the air so corrupted becomes more nourishing to plants: and the respiration observable in plants, is the reverse of that in animals; the latter take in pure air, and send it out foul and phlogisticated; plants take in this foul air, and return it purified.

It has now been farther discovered by Dr. Ingenhouz, that plants yield a pure air by means of the sun's rays acting upon them. As to their faculty of changing impure air

into pure by a process in their vessels after they have absorbed it, this is analogous to their faculty of elaborating sweet juices from impure earth and dung; whence it is reasonable that they should have a similar effect on foul air.

Sun raises a pure Air from Vegetables.

Soon after the sun is risen, he begins to raise this pure air from plants, by which the atmosphere in the day-time is rendered more wholesome than in the night; for plants in the night, or in the shade, have a contrary effect upon the air; but their bad effect in the night, is not nearly so great as their good effect in the day. It is remarkable that all flowers whatsoever hurt the air, both by day and by night, and we have heard of those who have lost their lives by sleeping with many flowers in a close room.

Water-plants are remarkably vigorous in this faculty of yielding pure air, to correct the inflammable air which is bred by the soil in low marshy grounds: whence it appears, that such places produce one of the best remedies for their own native evils; and thus do all things work together for good.

The plant of the *Nasturtium Indicum*, in the space of two hours, gives out more air than equals the bulk of all its leaves: what a quantity then must be discharged from lofty trees in a day's time! and how unhappy in all respects is the modern practice of leaving dwelling-houses so naked to a considerable distance, and destitute of plantation!

It is to be observed, that the act of vegetation alone is not sufficient to produce this salutary effect upon air; it is vegetation in the sunshine, from whence this good is to be expected*. Vegetation in a cellar, where the sun cannot act, produces a bad air.

Air transmuted from Light and Fire, rather than from Water.

And now an important question arises: whence is all this air produced, and what is it made of? Is it first absorbed as air, and then

* I have often wondered why a leaf should be cold when the sun has been shining upon it in a hot summer's day for several hours: the reason is, that the sun is continually producing a fresh cold air from all its pores. Hence it is that we are cooled by approaching near to trees and shrubs, on another principle, added to the common benefit of their shade.

then discharged again as better air? This cannot be the case; because the process goes on as well, if not better, under water; and this under such water as has no air of its own to part with. When a glass vessel, which has long contained water, has thereby contracted a green matter at the bottom, in which there is some slight principle of vegetation; this green matter, when the sun shines upon it, yields pure air from under the water, as from a source that is inexhaustible. "It is wonderful," says Dr. Ingenhouz, "that this matter seems never to be "exhausted of yielding dephlogisticated air, "though it has no free communication with "the atmosphere*." *Ex nihilo nil fit*: something there must be to make it out of; and as no new matter has access to make any alteration but the rays of the sun, this air must be elaborated out of them by a *transmutation*. Here I differ unwillingly from the ingenious experimenter above mentioned. The air, he allows, is not *in* the leaves out of which it proceeds, but elaborated *from* them by a *sort of transmutation*; but when he proceeds to explain himself farther, he is inclined to think it a transmutation from *water*.

But

* See his Treatise, p. 89.

But it may be from *light;* if the question can be determined, to which of these two air is more nearly allied, whether to fire or to water? And it will soon appear which of these has the best claim, if we consider what happens to the calx of metals, which presents us with a similar production of dephlogisticated air. When a metal is calcined by fire, either culinary or solar, it increases in weight, though it apparently loses much of its native matter by evaporation. The calx afterwards yields a pure dephlogisticated air. Therefore, if bodies impregnated with light or fire are afterwards found to yield air, no inference is so easy and natural as this, that quiescent fire, attached to their parts, is detached from them again in the *new form* of elastic air. Here *water* can have no share in the effect; and if not in this case, there is no occasion to suppose it in the other. I know what is urged in favour of a positive levitation, and of air absorbed in the form of air: but when we have recourse to these principles, we avoid a more easy and satisfactory solution, for the sake of one more difficult, and which will not stand the test of experiment.

Air chiefly infected by a sulphureous Principle.

From this experiment upon calces, it may be collected, that a sulphureous principle, however variously modified in the different sorts of air, is the principal cause of its insalubrity. By the calcination of a metal, its native sulphur is expelled by fire, and the air which it yields afterwards is a pure elementary principle; which, as it comes pure even from calces that are highly poisonous in themselves, cannot be supposed to derive any thing from the earthy subject out of which it is raised. That air will, therefore, be the most agreeable to animal life, which partakes least of sulphur; for sulphur, and all the modifications of it, (at least the *aerial,*) from whatever sources they may arise, whether from minerals under the earth, from marshy grounds, or smoking chimnies, is noxious to the lungs, and will generally have an ill effect on animal respiration. But such air will forward the growth of vegetables; and this is one reason why plants are large, lively and vigorous in and about the air of great cities, while the inhabitants are pale and unhealthy.

healthy. The great luxuriancy of vegetation on the lands in the neighbourhood of volcanos, is partly imputed to a sulphureous principle abounding in such places, and disseminated in the air. And this luxuriancy of vegetation in its turn assists in correcting that fault of the air by which itself is promoted.

Hence it becomes more easy to understand how the distemperature of the air was probably prevented in the former and purer ages of the world, and its qualities so accommodated as to give vigour and longevity to the human constitution. If the atmosphere was more free from sulphureous exhalations, less subject to putrefaction, and nearer to the condition of what is called dephlogisticated air, the benefit to human life must have been considerable. Some learned men have conjectured, from the phænomena of electricity both natural and artificial, that the sulphureous principle predominates in nature, in these latter ages of the world, more than formerly. It may be difficult to decide in a matter of such obscurity; but the subject seems worthy of consideration.

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did fly upon the wings of the wind. The wings of an eagle are also said to be given to those who are transported or conducted any whither by the divine assistance: thus it is said of the people miraculously rescued in their flight from Pharaoh, and conducted over the Red Sea, *Ye have seen what I did unto the Egyptians, and how I bare you on eagle's wings, and brought you unto myself.* See also another remarkable passage to the same purpose, Rev. xii. 14. Whoever considers the physical character of this bird, and its sacred appropriation among heathens and believers, will be pleased with the propriety of that custom which is still retained amongst us, of laying the Bible in our churches upon the wings of an eagle; for thus the bird of inspiration, carrying the book of inspiration, is employed to a purpose more honourable and salutary, than when it was supposed to be carrying thunder through the air for the use of Jupiter.

The mythological relation between the eagle and the air may perhaps enable us to find a more satisfactory account than has yet been given of one of the most recondite fables of antiquity. Prometheus is said to have been fastened to a rock, with an eagle

appointed

appointed to feed upon his liver, which grows again as fast as it is devoured. I have often suspected that this part of the fable of Prometheus has a physical meaning, and expresses nothing more at the bottom than the natural effects of air and fire upon one another. Prometheus is fire; the eagle is air: the liver of Prometheus is the brightness of fire, thus equivocally expressed, because the word כבד in the Hebrew and Phœnician had the two senses of *glory* and a *liver*. The immortal liver of Prometheus, always wasting and always growing, expresses the undecaying nature of fire, which the air is constantly working upon, and dissipating, and yet the defect is as constantly supplied; the more we borrow from fire, the more it grows.

There is one more circumstance relating to the eagle, which I look upon as fabulous, and think it must be accounted for nearly on the same principle as the former. The eagle is said to have a practice of flying against the rising sun, and of trying her young brood, by conducting them upwards in the air with the sun's rays in their eyes, in order to put the goodness of their nature to the test, and prove whether they are truly of the eagle kind. We can scarcely suppose

pose this to be literally true: and therefore, it was rather meant as a mythological signification of a philosophical doctrine; that the spirit of the world, signified by the eagle, is always flying toward the centre of the system in the common course of nature.

If we leave the mythologists, and proceed to the scripture, there we shall find the wind frequently alluded to as an emblem of the Divine Spirit: and the word being the same for both, it is not always clear which of them is intended, whether the Divine Spirit or the natural; as in that passage of the sacred cosmogony, where the Spirit is said to have moved upon the face of the waters. Some commentators take one side, some the other, and some both; as supposing that the divine creative power acted with the instrumentality of the air, which indeed seems to be the most reasonable and safest opinion.

The reason why the natural air is alluded to as an emblem of the Divine Spirit, is plainly this, because the operations and offices of the one are analogous to those of the other. The air supports natural life and motion; it refreshes those who are wearied with the burden and heat of the day; with reference to which, the scripture speaks

of

of the *times of refreshing from the presence of the Lord**, which shall succeed to the labours of those who are employed in his service. The air also gives sound and utterance in a physical sense, as the Divine Spirit gave the utterance of inspiration on the day of Pentecost; and therefore his presence on that occasion was announced by a *rushing mighty wind from heaven*†. False prophets, whose inspiration is spurious and without effect, are said to have the figure without the substance: Jer. v. 13. *their prophets shall become wind, and the word is not in them.*

The same idea was adopted by the heathens; with whom the infusion of prophecy, or of any supernatural influence, was always called *inspiration*, as if it were of a wind breathed into the mind. Persons so inspired were said to be *afflati numine*, blown upon by the Deity; and sometimes *inflati*, as if they were swelled and inflated with the influence of their gods. Homer uses the word εμπνεω for the act of divine inspiration; and a person

* Acts iii. 19. καιροι αναψυξεως, the times of refrigeration.

† Acts ii, 2.

a person endued with any supernatural power is called πεπνευμενος, a man inspired*. The agitations of Sibyls and Pythonesses are described by the poets, as proceeding from a sort of inflation; as in the case of Virgil's Sibyl,

> " ——————— pectus anhelum,
> " Et rabie fera corda tument: majorque videri
> " Nec mortale sonans, *afflata* est numine quando
> " Jam propiore Dei "——— Æn. vi. 48.

Under this persuasion, that the wind was the inspiring cause, the heathen augurs and prophets had recourse to mystical caverns of the earth, and subterraneous *spiracula*, to catch a sort of divine air; which coming upwards from the earth, was contrary in every sense to that wind which on the day of Pentecost came down from heaven: thus we read in the sixth book of Virgil's Æneid,

> " ——— Horrendæque procul secreta Sibyllæ
> " Antrum immane petit "———

And again,

> " Excisum Euboicæ latus ingens rupis in antrum."
> Æn. vi. 10. 42.

But no example of this kind is more to our present purpose, than Justin's description of the famous temple at Delphi; where the priestess

* Vid. Il. O. 60. K. 482. Γ. 148.

priestess of Apollo gave oracular answers. This temple was placed on a rock surrounded with precipices. The highest part of it was hollow like an amphitheatre, in which the sound of the voice, or a trumpet, was wonderfully increased and multiplied. About half way up the mountain, where the ground was flat, there was a deep chasm in the rock, out of which there issued a cold spirit, which went up aloft as a strong wind; and by this the prophets, when inspired, were put out of their wits, and, being filled with the deity, were compelled to give answers to those who consulted them*. Pliny makes mention of this wonderful chasm at Delphi, and admits the extraordinary circumstance, that the priests were infatuated with the exhalation when they uttered their predictions†. I think it not improbable that the residence of the Cumæan Sibyl was by the Mephitic ca-

* In hoc rupis anfractu, mediâ fere montis altitudine, planities exigua est, atque in ea profundum terræ foramen, quod in oracula patet: ex quo frigidus spiritus, vi quadam velut vento in sublime expulsus, mentes vatum in vecordiam vertit, impletasque Deo, responsa consulentibus dare cogit.

† Alibi fatidici specus, quorum exhalatione tremulenti (falsely for *temulenti*) futura præcinunt; ut Delphis, nobilissimo oraculo. Plin. lib. ii. cap. 93.

vern of the Grotto del Cani in the neighbourhood of Naples, or some other of the like quality. That it was a cavern in a rock is plain from Virgil's description of it.

To us who live in the latter ages of the world, and have an opportunity of comparing our modern heathens with the heathens of antiquity, the inconsistency of error is very notorious, and ought to be seriously considered. In the days of Homer, nothing was to be heard of but consultations with the deity; no step was to be taken in any great affair without auguries, oracles, sacrifices, and prophetic dreams*: every notable action was imputed to the presence of some divine assistance; and even human wisdom and prudence ascribed their superiority and success to open or secret inspiration. This was the fashion with the wisest nations, in those days, when the true God was more conversant with men, and gave answers to his people by priests and prophets. They that had apostatised from the true religion never thought of denying the fact of inspiration: they attempted to exceed it, and drown the fame of it, by making a greater figure

* Αλλ' αγε δε τινα μαντιν ερειομεν, η ιερηα
Η και ονειροπολον (και γαρ τ' οναρ εκ Διος εστιν) Il. i. 62.

figure with other miracles and inspirations of their own; and their histories and compositions of every kind abound with them. But now the age of inspiration and miracles is past; the adversaries have changed their ground: human reason, which of old could do nothing without divination, is now sufficient of itself for every thing. Instead of applying to the Deity for wisdom and information, a new philosophy instructs us, that every man has an oracle in his own breast, and that natural reason will answer all the purposes of revelation. Thus does the fashion alter with times and occasions: error changes its posture, but is no nearer to truth than it was before. The new philosopher, who looks with pity upon the heathen conjurors, his predecessors, is the slave of delusion in another shape; and he that now writes against the possibility of miracles, and mocks at all pretensions to inspiration, because he has no taste for the religion which God hath revealed, would have sucked in the intoxicating wind of Delphi, and employed his parts in studying the flight of crows or the pecking of chickens, if he had lived in the proper age of the world.

Something farther should be said here con-

cerning Pythonic inspiration, as related to the worship of the serpent; a species of idolatry very common among the heathens, and in appearance the most shocking and unaccountable of any. It certainly prevailed in Egypt, at Hierapolis, in most of the nations of Europe, and in the East and West Indies, a large dragon having been discovered by the Europeans in a temple at Mexico. The name *Python* is used for a serpent, to which Ovid adds the epithet of *tumidus Python*, the swelling serpent *. The *spirit of divination*, spoken of Acts xvi. 16. is called πνευμα πυθωνος, a spirit of Python; which, in the Hebrew of the Old Testament, is called אוב *ob*, and translated *a diviner*, from the persons so inspired being swoln in the belly like leathern bottles blown up with wind, or a carcase inflated with putrefaction: which idea is also comprehended under the verb πυθω, whence the Latin *puteo, to stink* or *putrify*. From the Hebrew *ob*, the Greek οφις was probably derived; for we find the like

* ——— Te quoque, maxime Python,
Tum genuit, populisque novis, incognite serpens,
Terror eras ———

* Stravimus innumeris tumidum Pythona sagittis.
Ovid. Met. lib. i. 438. 460.

like affinity between the senses of the word נחש, *nahash*, a serpent, which also signifies *divination* and *prophecy;* as if the serpent were recognized as the grand inspirer of the heathen prophets. In Leigh's Critica Sacra, the words אוב and אובות are thus explained by that learned interpreter: "Utres, la- "genæ, quibus vinum continetur, deporta- "tur, aut asservatur: semel reperitur in "scripturâ, Job xxxii. 19. Inde videtur "dici אוב Pytho, quod obsessi, velut utres "inflati turgescant, et spiritus immundus ex "illorum ventre, de præteritis, præsentibus "et futuris interrogatus respondeat. Unde "etiam εγγαστριμυθοι ventriloqui dicuntur." Origen, and other Christian writers, objected to their heathen adversaries, as a known fact, the horrid mode in which the priestesses of Horus Pythius, or the Delphic Apollo, received their inspirations—"Ori Pythii spe- "cus insidens, quam vocant prophetidem, "per muliebria recipiebat spiritum Apollinis "fatidicum *." The Pythonesses are said to have been delivered of their oracles after the same form, and were therefore called εγγαστριμυθοι, because they seemed to speak from their

* Orig. contr. Cels. lib. iii.

their bowels; and for the conception of this hypogastric inspiration, they used to sit upon a tripod, which was a mystical stool with three feet; or over a hole of the earth in one of their consecrated caverns, and so became inflated with the spirit of the Python. Cælius Rhodiginus, in his Lectiones Antiquæ, which contain a large and curious collection of the more recondite articles of ancient literature, declares that he once met with a ventriloquist, to whose faculty of speaking from the lower regions of the body, he was an eye and ear-witness, in company with many other people. As the age of Pythonism had certainly expired before he wrote, the account has too much of the marvellous to be credited in all its circumstances.

"It would be a noble undertaking," says Mr. Bryant, "and very edifying in its consequences, if some person of true learning, and a deep insight into antiquity, would go through with the history of the serpent *." No person of this age is better qualified for such an undertaking than the author of this observation, who has already given much light into the subject. I have one hint to offer, which, if it is well founded,

* Vol. i. p. 490.

founded, might be of use in such an inquiry; that the serpent, which with heathen mythologists had various acceptations, was also understood as a natural symbol or hieroglyphic of the air. The Dragon, which is said to have been the associate of Bel, or Belus, (the same with the Jupiter of the Romans,) had probably this meaning as an idol, either from the serpentine motion of the air, or some other physical properties which will admit of a like accommodation. The air was undoubtedly worshipped under the name of Jupiter; and the form of a serpent was judged consistent with his character, as appears from the story which Plutarch has related of Alexander's mother, that Jupiter Ammon, in the form of a serpent, was declared by the oracle at Delphi to have been the real father of that hero *. They who give a philosophical turn to the heathen fables, (which, under proper restriction, is not done without good reason,) suppose that the fable of Apollo, destroying the serpent Python with innumerable arrows, was intended to signify figuratively the power of the sun's rays in subduing and correcting the poisonous air and vapour which arose from the earth

* See Plutarch in Vit. Alexandri.

earth after the deluge. The Scripture has a passage where the serpent seems to be spoken of in the like sense as a symbol: Job xxvi. 13. *By his spirit he hath garnished the heavens, and his hands have formed the flying serpent.* If the latter member of this verse is exegetical of the former, which is very usual in the sacred writings, then the serpent is here synonymous either with the *spirit* or the *heavens:* and if so, this might lead to some farther discovery concerning the figurative relation between the serpent and the elements, if the proper materials were at hand.

THE END OF THE NINTH VOLUME.

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